THE MINERALOGICAL MAGAZINE

AND

JOURNAL OF

THE MINERALOGICAL SOCIETY

No. 165 June, 1939 Vol. XXV

Biographical notices of mineralogists recently deceased. (Seventh series.)[1]

By L. J. Spencer, C.B.E., M.A., Sc.D., F.R.S.

Formerly Keeper of Minerals in the British Museum.

[Read March 9, 1939.]

IN the following list of thirty lives, with a range in ages from 32 to 93 years, the average age is 72·7 years. As shown in the table below, there has been a steady increase in the average age throughout the series.

Series.	Period.	Min. Mag. vol.	No. of lives.	Total years lived.	Average age.
—	1876–1919	1–18	210	13,271	63·2
I.	1919–21	19	43	2,738	63·6
II.	1921–24	20	49	3,317	67·7
III.	1924–27	21	42	2,858	68·0
IV.	1927–30	22	39	2,660	68·2
V.	1930–33	23	41	2,899	70·7
VI.	1933–36	24	36	2,556	71·0
VII.	1936–39	25	30	2,180	72·7
			490	32,479	av. 66·3

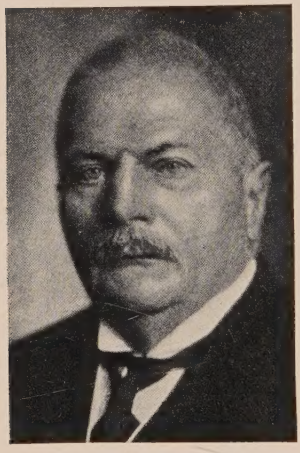
Bourgeois (Léon Zéphirin) [1856–1938], French chemist, was born in Paris on August 26, 1856, and died on March 22, 1938. Since 1880 he was chemical assistant in the Natural History Museum in Paris, retiring with the title of honorary sub-director. Since 1884 he was also assistant at the Polytechnic School. His doctoral thesis in 1883 was on the artificial reproduction of minerals, and in 1884 he contributed a long section (240 pp.) on this subject to Frémy's chemical encyclopaedia. The preparation of many other minerals and allied compounds was described

[1] Series I–VI in Min. Mag., 1921–36, vols. 19–24. An index to earlier notices in vols. 1–18 (1877–1919) is given in vol. 19, pp. 259–262, and to later notices in series I–V in vol. 23, pp. 364–366. A mortality curve is given in vol. 20, p. 253.

in later papers. He was an original member of the French Mineralogical Society in 1878, and since 1896 its treasurer.

A portrait of him appears in P. N. Chirvinsky's book on artificial minerals (Kiev, 1903–6, p. 320).

Brauns (Reinhard Anton) [1861–1937], German mineralogist, and an Honorary Member of this Society since 1926, died at Bonn on January 28, 1937, after a week of suffering with a fractured skull. He had been knocked down by a tram-car when crossing the street. He was born at Eiterfeld near Kassel on August 20, 1861, and studied at the University of Marburg, taking his degree there in 1885. During 1883–94 he acted as assistant in the Mineralogical Institute at Marburg, the first year under F. Klocke and afterwards under Max Bauer. In 1894 he was appointed Professor of Mineralogy and Geology in the Technical High School at Karlsruhe; afterwards succeeding A. Streng at the University of Giessen in 1895, J. G. Lehmann at Kiel in 1904, and H. Laspeyres as Professor of Mineralogy and Petrography at Bonn in 1907. Due to retire in 1928, he was then made Emeritus Professor, but continued to act until 1934, when he was succeeded by K. Chudoba. He was also Honorary Professor in the Agricultural Academy at Poppelsdorf from 1907 to 1929.



R. Brauns (in 1931).

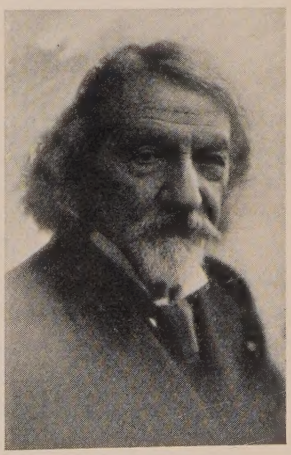
Brauns's first work was on the optical anomalies of crystals, commencing with a paper in 1883, his inaugural dissertation in 1885, and a prize essay in 1891, the last a classical work of 370 pages. Several other useful books were written by him. His small elementary 'Mineralogie', which appeared in 1893 and reached a seventh edition in 1936, had a circulation of more than 100,000 copies.[1] His 'Chemische Mineralogie' (1896) was the first book of the kind and was translated into Russian. 'Das Mineralreich' (1903–4), a large quarto volume written on popular lines and illustrated with 91 plates, many of them in colour, was translated into English ('The Mineral Kingdom', 1908–12), Italian, Russian, and Czech. Other books deal with the minerals and rocks of the Laacher

[1] The number 10,000, stated in Min. Abstr. 6–339, was of each edition and reprint.

ee district, volcanoes and earthquakes, determination of minerals, and quid crystals. From 1917 to 1934 he was one of the editors of the Neues Jahrbuch and Centralblatt für Mineralogie, to which he contributed numerous reviews and abstracts. Many of his original papers ealt with the Laacher See district, where he made a large collection of inerals and rocks which occupy a special room in the University at onn. He had paid annual visits to this locality, and his last wish was hat his ashes should be scattered in the lake. A branch of mineralogy n which he was specially interested, ever since his first visit to Oberstein n 1883, was that of gemstones, and more particularly those produced y artificial means. On the day of his accident he had finished a note n the secret of zircon. He was one of the founders of the German Mineralogical Society in 1908, its President in 1921–4, and he was elected n honorary member in 1931.

A Festband Reinhard Brauns, Neues Jahrb. Min., Abt. A, 1931, Beil.-Bd. 64, ontained a biography, bibliography, and portrait. The bibliography has been xtended to 191 items by K. Chudoba, Zentr. Min., Abt. A, 1937, pp. 97–102, with ortrait. Other notices by K. Chudoba, Deutsche Goldschmiede-Zeitung, 1937, o. 7, with portrait; and by E. H. Kraus, Amer. Min., 1938, vol. 23, pp. 131–133, ith portrait.

Cesàro (Giuseppe Raimondo Pio) [1849–1939], Emeritus Professor f Crystallography and Mineralogy in the University of Liége, was born t Napoli (Naples) on September 7, 1849, and died at Comblain-au-Pont ear Liége on January 20, 1939. His brother, Ernesto Cesàro [1859–907] was Professor of Mathematics in ne University of Napoli. At the age of xteen he was sent to Liége to learn rench and prepare for entry into the ining school of that university, but is not being to his taste and owing to lness and family misfortunes, he was bliged after two years to abandon this nd to earn his living by private teaching. fter several years, in 1891, he returned o the university, still without diploma, nd was placed in charge of the course n crystallography and mineralogy, be-oming extraordinary professor in 1895, rdinary professor in 1900, and emerited n 1919, but continuing to teach until



G. Cesàro (in 1928).

1921, when he was succeeded by his pupil H. Buttgenbach. As honorary director of the mineralogical collection he continued working until the end. During the War he was a refugee in Cambridge, where he worked on the Vesuvian minerals in the collection, and he wrote, in French, three papers on mathematical crystallography for this Magazine (vol. 17). He had been an honorary member of our Society since 1909, and in 1917 was elected one of the very few honorary members of the French Mineralogical Society. He was a corresponding member of the Paris Academy of Sciences since 1930, and was twice President of the Belgian Academy of Sciences. He was naturalized as a Belgian citizen in 1888.

He was the author of numerous papers on the crystallography and optics of various minerals, mostly from Belgian localities, and later from Vesuvius. In the Royal Society's Catalogue of Scientific Papers 117 titles are listed under his name for the years 1883 to 1900. These papers were presented in a pedagogic style often at great length and with masses of working detail—even logarithmic calculations—quite camouflaging any original matter that they might contain. Some were merely recapitulations and criticisms of other authors' papers, as if correcting a pupil's exercise. He described as new minerals cornetite, fraipontite, koninckite, richellite, and valleite; and cesarolite bears his name.

A. Lacroix, Compt. Rend. Acad. Sci. Paris, 1939, vol. 208, pp. 397–399.

Coleman (Arthur Philemon) [1852–1939], Emeritus Professor of Geology in the University of Toronto, was born at Lachute, Quebec, on April 4, 1852, and died at Toronto on February 27, 1939. He was educated at Victoria University, Cobourg, Ontario (B.A., 1876), and Breslau University (Ph.D., 1881), and on returning from Germany was appointed Professor of Geology and Natural History in his old university at Cobourg in 1882. From there he passed to Toronto, where he was professor from 1901 to 1922, and during 1893–1909 he was also geologist to the Ontario Bureau of Mines. His first paper in 1887 gave a description with chemical analysis of the Iron Creek meteorite from Alberta. His work on the mineral deposits of Canada, especially of nickel in the Sudbury district, included petrographical studies, and the rock names sudburite and heronite are due to him. Much of his work, however, related to glacial geology and geography. He had been President of the Royal Society of Canada, the Canadian Institute, and the Geological Society of America, and was elected a Fellow of the Royal Society of London in 1910.

Award of Penrose medal, Proc. Geol. Soc. Amer., 1937, for 1936, pp. 50–54, with portrait. T. C. Phemister, Nature, London, 1939, vol. 143, pp. 547–548.

Collins (William Henry) [1878–1937], Director of the Geological Survey of Canada, was born at Chatsworth, Ontario, on October 26, 1878, and died at Ottawa on January 14, 1937. After graduating in geology at the University of Toronto in 1904 he was for a year assistant under T. L. Walker in the department of mineralogy. He then continued his studies at Heidelberg, Chicago, and the University of Wisconsin, and in 1906 joined the Geological Survey of Canada, becoming Director in 1920. Important work was done in several of the mining districts, especially in the Sudbury nickel field. He was President of the Geological Society of America in 1934. The mineral collinsite was named after him.

E. S. Moore, Canadian Mining and Metallurgical Bulletin, 1937, no. 298, pp. 47–49, with portrait. A. Knopf, Amer. Journ. Sci., 1937, ser. 5, vol. 33, pp. 397–398. T. T. Quirke, Proc. Geol. Soc. Amer., 1938, for 1937, pp. 157–168, with portrait and bibliography.

Thomas Crook (1876–1937), a Vice-President of this Society, was born at Burnley in Lancashire on January 12, 1876. Starting life as a weaver, he attended evening classes at the Burnley Mechanics Institute, and in 1898, on the examination results of the old Science and Art Department, he gained a Royal Exhibition tenable at the Royal College of Science for Ireland. There, in Dublin, he took the associateship (A.R.C.Sc.I.) in natural science in 1901, and then became assistant in geology and mineralogy to the late Professor Grenville A. J. Cole. In 1905 he joined the scientific department of the Imperial Institute in London, and for six years (1919–25) was chief of the intelligence and publications section of the new Imperial Mineral Resources Bureau, which was afterwards amalgamated with the Imperial Institute. Since 1928 he was Principal of the Mineral Resources Department of the Imperial Institute.

T. Crook (in 1922).

While in Dublin he described (with Cole) rocks dredged from the Atlantic; and worked on the mechanical analysis of soils for which he designed a special form of elutriator. Work of the latter kind was continued in London in connexion with the examination of sands and

concentrates collected by the mineral surveys in the colonies; and in addition to papers on the electromagnetic and electrostatic separation of minerals, he contributed to Hatch and Rastall's 'Petrology of the sedimentary rocks' (1913) a useful appendix on 'The systematic examination of loose detrital sediments'. Excellent mineralogical papers on geikielite, carnotite, strüverite, and ankerite in coal, on pleochroism and idiophany in mineral plates, and on the genetic classification of rocks and ore deposits were published in this Magazine. This promising scientific work, up to 1914, became eclipsed by a vast number of well-written articles and abstracts on the occurrence and possible uses of a great variety of mineral products, most of which appeared anonymously in the Bulletin of the Imperial Institute. With the foundation of the Imperial Mineral Resources Bureau in 1919 a still more intensive period followed, and then was issued a long series of useful pamphlets and books dealing with some fifty kinds of minerals and ores, each complete in itself and with several editions bringing statistics up to date. A useful text-book is his 'Economic Mineralogy' (1921), and another book, 'History of the theory of ore deposits' appeared in 1933.

Crook had been a member of this Society since 1907, and he was elected a Vice-President in November 1936. In the same year he had been awarded the O.B.E., and in December the honorary degree of B.Sc. was conferred on him by the National University of Ireland. He died on January 6, 1937, after an abdominal operation, at the early age of very nearly 61.

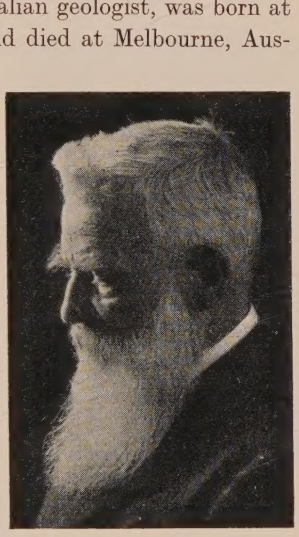
L. J. Spencer, Nature, London, 1937, vol. 139, p. 141. Bull. Imp. Inst. London, 1937, vol. 35, pp. 67–68. W. F. P. McLintock, Quart. Journ. Geol. Soc. London, 1937, vol. 93, pp. xcix–c. S. J. Johnstone, Proc. Geol. Assoc. London, 1938, vol. 49, p. 101.

Dolivo-Dobrovolsky (Vadim Vladimirovich), Доливо-Добровольский (Вадим Владимирович) [1904–36], Russian crystallographer, was born at Krasnoye Selo near St. Petersburg on June 20, 1904, and died at Moscow on September 1, 1936. He graduated in 1926 at the Mining Institute in Leningrad, afterwards acting as demonstrator, and in 1927–30 was lecturer in crystallography in the University of Tashkent. Returning to the Mining Institute in Leningrad in 1930, he was first assistant and later (1934–6) professor of crystallography, with an interval (1932–4) as professor in the Leningrad Polytechnic Institute. He did intensive work on mathematical crystallography, publishing his first papers before graduation [M.A. **3**–160, 240, 447], while his last papers appeared after

is early death [M.A. 7–167, 241]. Other important papers were published in collaboration with Professor A. K. Boldyrev [M.A. 6–79, 462]. The devising of a new notation and special names for each of the 230 space-groups must have involved some mental strain.

Mém. Soc. Russ. Min., 1936, ser. 2, vol. 65, pp. 466–469, with bibliography and portrait.

Dunn (Edward John) [1844–1937], Australian geologist, was born at Bristol, England, on November 1, 1844, and died at Melbourne, Australia, on April 20, 1937, at the advanced age of 92. He went with his parents to Australia in 1849, and at the age of sixteen he entered the Land Survey Office at Beechworth, Victoria. At that place he found stones enclosing water (enhydros), which were the subject of his first paper in 1870, and he presented specimens of these to the British Museum in 1865. In 1864 he joined the Geological Survey of Victoria, and continued in its service until it was abolished in 1869. In 1871 he went to South Africa, visiting first the newly discovered diamond fields of which he gave accounts before the Geological Society of London. His geological map of South Africa was published in 1875 and 1887, in which he predicted the extension of the gold-bearing reefs in the Transvaal. An interesting lilac-coloured mineral was found in 1883 and specimens sent to the British Museum, but unfortunately wrongly labelled kämmererite; it later proved to be stichtite, which was not described as a new mineral from Tasmania until 1910 [M.A. 1–47, 339]. He returned to Victoria in 1886, continuing his work as a consulting geologist; and in 1904 he was appointed Director of the Geological Survey of Victoria in succession to J. W. Gregory, from which post he retired in 1912.



E. J. Dunn (in 1927).

Dunn had collected pebbles so long ago as 1856, and he wrote a book 'Pebbles' (Melbourne, 1911) with 250 illustrations. This collection he presented to the British Museum in 1934. Other donations to the British Museum included his collection of australites. He was especially interested in these strange bodies and had propounded a theory to account

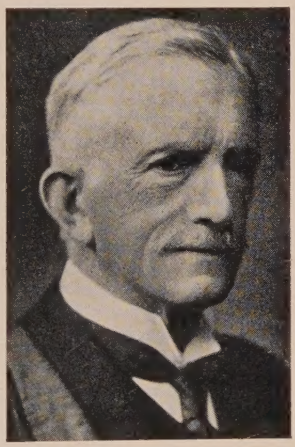
for their origin. In addition to numerous reports on mining properties, he published a book on 'Geology of Gold' (London, 1929) and one on 'The Bushman' (London, 1931). His ethnological collection of Bushman objects from South Africa was given to the Pitt-Rivers Museum at Oxford.

A chronological series of biographical notes and bibliography, compiled by his daughter Miss Lilian G. Dunn, has been published with an appreciation by J. V. Želízko, 'Geologist Edward John Dunn' (Prague, 1937, 19 pp., with portrait). Other notices of his life and work have appeared in Industrial Australian and Mining Standard, Melbourne, 1924, vol. 72, p. 634; ibid., 1937, vol. 92, pp. 114–115. Victorian Naturalist, 1937, vol. 54, pp. 20–22, with portrait. A. W. Rogers, Trans. Geol. Soc. South Africa, 1937, annexure to vol. 39, pp. 88–96, with portrait.

Gossner (Balthasar) [1877–1937], German mineralogist, was born at Zaiertshofen, Bavaria, on January 3, 1877, and died at Krumbach, Bavaria, on November 7, 1937, after an operation for gall-stones. Studying at München, Würzburg, and Leipzig, he graduated at München in 1902 under P. Groth, and was assistant there in 1900–4 and 1907–8. During the interval he was engaged on chemical work in the soil laboratory of the Forestry Institute, and from 1908 was a teacher in a high school in München. In 1920 he was appointed Professor of Mineralogy, Crystallography, and Petrography in the University of Tübingen, and in 1925 he succeeded P. Groth as Professor of Mineralogy and Crystallography and Director of the Bavarian State collection of minerals in München. His earlier work consisted of crystallographic measurements of many organic and inorganic compounds made chiefly for the purpose of filling gaps in Groth's 'Chemische Krystallographie' (1906–19). A book on crystal calculation and drawing was issued in 1914. During his time in Tübingen he published a series of papers on the chemical constitution of silicates, regarding them as complex double salts, and the results were collected together in his 'Lehrbuch der Mineralogie' (1924). On his return to München intensive work was done on the silicates by X-ray methods, and a long series of papers was published, often as joint papers with several of his pupils. (Groth had inspired and directed the work of a long succession of pupils, but his name never appeared as joint author.) This work was extended to many other minerals, and analogies were drawn between silicates and phosphates and sulphates, but these relationships and the chemical formulae deduced are perhaps rather forced.

H. Steinmetz, Sitzungsber. math.-naturwiss. Abt. Bayer. Akad. Wiss. München 1938, pp. 82–84. F. Mussgnug, Zentr. Min., Abt. A, 1938, pp. 61–62. A portrait appears in the group taken in 1926, Min. Mag., vol. 21, pl. II.

HUTCHINSON (Arthur) [1866–1937], Emeritus Professor of Mineralogy in the University of Cambridge and a past-President (1921–4) of this Society, was born in London on July 6, 1866, and died in Cambridge on December 12, 1937. At the age of nine he lost his father, a London merchant, and his mother then returned to her native village of Culgaith in Cumberland; afterwards moving to Clifton for her son's education at Clifton College, and then to Cambridge. He entered Christ's College with a scholarship in 1884, and in 1888 obtained a first class in Part II of the Natural Sciences Tripos in chemistry, with mineralogy as a subsidiary subject. The following year a new cubic form of bismuth trioxide was discovered, a chemical analysis made of haematite pseudomorphous after pyrite (Min. Mag. **8**–184), and a crystallographic description given of zinc oxide from a blast-furnace (Min. Mag. **9**–5). Then at Würzburg under Emil Fischer he took the Ph.D. degree with a thesis on the reduction of aromatic amides, and also studied physics under Röntgen and mineralogy under Sandberger. Later, in 1895, he had also spent a few months in München studying crystallography under Groth. Returning to Cambridge in 1891 he was demonstrator and assistant lecturer in chemistry at Gonville and Caius College. As a student attending his first course of lectures I was impressed by the amount of mineralogical information that he imparted. (It is not fully appreciated by all chemists that all their inorganic materials are obtained from minerals.) In 1892 he was elected to a fellowship of Pembroke College with the duty of supervising the science students. After occupying various other college posts he eventually became Master (1928–37). He was also kept busy on several university boards and syndicates, on some of which he was secretary or chairman. In 1895 he was appointed demonstrator in mineralogy with promotion to the status of university lecturer in 1922. He was a very successful teacher and during this period most of the work of the department fell on him, but with a low salary. Eventually, in 1926, he was appointed to the professorship in which he had only a short run until 1931. His predecessor, W. J. Lewis, had hoped to create



A. HUTCHINSON (in 1929).

a record in the length of tenure of office of Cambridge professors. Sedgwick and Hughes had sat tight in the geology chair for 99 years (1818–1917). Lewis's ambition to make, with Miller, a century for mineralogy fell short at 94 (1832–1926). This was very hard on Hutchinson, but he bore it philosophically, and in the end he had the satisfaction of being both Professor and Master of his college.

Hutchinson's published papers were relatively few in number, and what he considered worthy of being placed on permanent record was expressed clearly and concisely. He believed in quality rather than quantity. Specially noteworthy is his first mineralogical paper in 1899 (Min. Mag. **12**–274) describing a new mineral, a silico-stannate of calcium which he named stokesite after Sir George Stokes. This he found in the Cambridge collection as one small crystal, which had been previously passed over as gypsum. Strenuous efforts to find more of this interesting mineral failed, and after a complete determination of the crystallographic, optical, and chemical characters there remains half of this unique crystal carefully preserved in the Cambridge collection. Other papers dealt with the diathermacy and optical characters of stibnite. He designed a universal goniometer and devised several ingenious graphical methods for use in crystallography, including the very useful 'Hutchinson Stereographic Protractor' and a crystallographic slide-rule. Lengenbachite from the Binn valley in Switzerland was analysed by him, and another mineral from this locality has been named hutchinsonite, one of the three known thallium minerals. In the first eleven volumes (1905–16) of the Annual Reports of the Chemical Society he contributed valuable reports on mineralogical chemistry.

He had been a member of this Society since 1890, often acting on the council, and as vice-president, president (1921–4), librarian, and foreign secretary (1931–7). He was elected F.R.S. in 1922 and was a vice-president of the Royal Society in 1933–4. After his retirement from the mastership of Pembroke College on September 30, 1937, he went to America, visiting his son at Yale University; returning ill, he died a few days after reaching his new home in Cambridge, where he had hoped to continue mineralogical work that had been delayed by administrative duties. In spite of his somewhat delicate health he was a great worker, and he had two serious breakdowns through overwork.

Nature, London, 1937, vol. 140, p. 1087. C. E. Tilley, Quart. Journ. Geol. Soc. London, 1938, vol. 94, pp. cxxiii–cxxiv. Sir William Bragg, Proc. Roy. Soc. London, Ser. A, 1938, vol. 169, p. 1. W. C. Smith, Obituary Notices of Fellows of the Royal Society, 1939, vol. 2, pp. 483–491, with portrait and bibliography. W. H. Mills, Journ. Chem. Soc. London, 1939, pp. 210–213.

Jackson (*Sir* Henry, *Baronet*) [1875–1937], formerly a member of our ociety (1899–1916), made chemical analyses of several of the lead lpharsenite minerals from the Binn valley in Switzerland described by . H. Solly in this Magazine. Born at Heywood in Lancashire on August , 1875, he was science lecturer and tutor of Downing College, Cam- idge (1901–11), afterwards taking medical degrees at Edinburgh in 14. After serving as major in the Royal Army Medical Corps during e War, he settled in Wandsworth as a medical practitioner, where he as afterwards Mayor and Member of Parliament. He was a Trustee of e London Passenger Transport Board and Chairman of the Standing mmittee on Mineral Transport. He collapsed and died whilst address- g a political meeting in Battersea on February 23, 1937.

Kalkowsky (Ernst Louis) [1851–1938] was born at Tilsit in East russia on September 9, 1851, and died at Dresden on February 13, 1938. pupil of Zirkel, he graduated at Leipzig in 1874, and was afterwards -istant there. In 1886 he was appointed Professor of Mineralogy and ology in the University of Jena, and in 1894 at the Technical High hool in Dresden, and Director of the State Museum of Mineralogy, ology, and Prehistory in the Zwinger at Dresden. His petrographical rk included an account of silicification of rocks in the Kalahari Desert 01), and a book 'Elemente der Lithologie' (1886). Mineralogical work s on nephrite occurrences and implements, struvite, tenorite, olivine ins, opalescent quartz, &c. The mineral kalkowskyn was named after n.

Zeits. Deutsch. Geol. Gesell., 1938, vol. 90, p. 173.

Karpinsky (Alexander Petrovich), Карпинский (Александр Петрович) 47–1936], Russian geologist, was born, the son of a mining engineer, Bogoslovsky in the Urals on January 7, 1847 (old style, December 26, 46), and died near Moscow on July 15, 1936. Graduating in 1866 at e Mining Institute of St. Petersburg, he joined the staff in 1869 and er (1877–96) was Professor of Geology. He had a hand in the founda- n of the Russian Geological Committee (= Survey) in 1882, and was first director, 1885–1903. Elected a member of the Russian Academy Sciences in 1886, he was president for twenty years (1916–36). He s also president of the Russian Mineralogical Society. He was elected Foreign Member of the Geological Society of London in 1901 and arded the Wollaston Medal in 1916. Although best known for his rk on stratigraphy, tectonics, and palaeontology, much of his early

work was petrographical, and he was one of the first in Russia to examine thin slices of rocks under the microscope. His first paper, in 1869, was on pyroxenites from the Urals, when he gave the rock-name muldakaite. Several of his papers also dealt with ore deposits and economic minerals. He visited London in 1935 on the occasion of the centenary celebrations of the Geological Survey and the opening of the new Geological Museum; and he had been elected honorary president for the XVIIth International Geological Congress which met in Russia in 1937.

A. Borissiak [A. A. Borisyak], Nature, London, 1936, vol. 138, p. 495. S. I. Tomkeieff, Quart. Journ. Geol. Soc. London, 1937, vol. 93, pp. xciii xcv. I. P. Tolmachov, Proc. Geol. Soc. Amer., 1937, for 1936, pp. 175–206, with portrait and bibliography. A. P. Gerasimov, Mém. Soc. Russ. Min., 1936, ser. 2, vol. 65, pp. 215–218, with portrait. E. V. Milanovsky, Bull. Soc. Nat. Moscou, 1936, Sect. Géol., vol. 14 (6), pp. 475–486, with portrait. A. A. Borisyak, Bull. Acad. Sci. URSS, Cl. Sci. Mat. Nat., Sér. Géol., 1937, pp. 591–598 (Russian), pp. 599–606 (French), with portrait. D. S. Belyankin, 'A. P. Karpinsky's petrographical heritage', ibid., pp. 607–632 (Russian), pp. 632–636 (French). A series of 17 articles by various authors in Природа (Priroda, Acad. Sci. USSR), 1936, no. 10, pp. 5–63, with portraits. Problems of Soviet Geology, 1936, vol. 6, pp. 651–655, with portrait. A separate pamphlet Александр Петрович Карпинский, Указатель основных работ [Aleksandr Petrovich Karpinsky, Indication of principal works] has been issued by the Academy of Sciences (1936, 33 pp., with portrait and bibliography, price 1 ruble).

Kitson (*Sir* Albert Ernest) [1868–1937], geologist, was born at Manchester on March 21, 1868, and died at Beaconsfield, Buckinghamshire, on March 8, 1937. At the age of one year he was taken to India, where his father, John Kitson, had a school, and at the age of six he was taken to Australia. In 1886 he entered the Land Department of the Civil Service of Victoria. Attending evening classes at the Melbourne Technical School, he became specially interested in geology and mining, and these subjects were further studied at the University and the School of Mines. In 1899 he was transferred to the Geological Survey of Victoria, on which he later became senior geologist and for a time acting director. The mineral surveys of the colonies instituted by the Colonial Office in connexion with the Imperial Institute afterwards developed

Sir Albert Kitson (in 1931).

to geological surveys, and Kitson was one of the first to enter this rvice. He gave a good account of the utility of such surveys in his residential address to the geology section of the British Association eeting in South Africa in 1929. In 1906–11 he was in charge of the ineral Survey of Southern Nigeria, where important deposits of black d brown coal were discovered. In the Gold Coast during 1913–30, st as Principal of the Mineral Survey and afterwards as Director of e Geological Survey, further discoveries of economic importance were ade—large deposits of manganese ore in 1914, diamonds in 1919, and ge deposits of high-grade bauxite still to be developed. After his tirement from the Gold Coast survey in 1930 he reported on gold-fields Kenya Colony. Kitson was a most energetic little man; his constant mpanion was a small prospecting pan. I well remember a journey with m in 1924 in the mining districts of northern Ontario: at every halt the train he was out with his little pan in any ditch he could find. In ognition of his useful work in the colonies he was awarded C.B.E. in 8, C.M.G. in 1922, and a knighthood in 1927. The Geological Society London awarded him the Wollaston Fund in 1918 and the Lyell Medal 1927. He became a member of our Society in 1917 and served on the uncil in 1930–3.

Bull. Imp. Inst. London, 1937, vol. 35, p. 68. W. Cullen, Nature, London, 1937, l. 139, pp. 576–577. E. O. Teale, Proc. Geol. Assoc. London, 1938, vol. 49, pp. 104–. J. F. N. Green, Quart. Journ. Geol. Soc. London, 1938, vol. 94, pp. cxxv–cxxvii.

Klockmann (Friedrich Ferdinand Hermann) [1858–1937], German neralogist, was born on April 12, 1858, at Schwerin in Mecklenburg, d died on November 17, 1937, at Aachen. Studying at the Clausthal ning Academy and Berlin, he graduated at Rostock in 1881, and was en attached to the Prussian Geological Survey. In 1887 he was ap-inted Professor of Mineralogy and Geology in the Clausthal Mining ademy, passing in 1899 to the Technical High School at Aachen, ere in 1922 he was succeeded by H. Schneiderhöhn and afterwards by Ramdohr. Minerals described by him include copper selenides from e Sierra de Umango in Argentina, one of which he named umangite, d another copper selenide from the same locality has since been named ckmannite. His 'Lehrbuch der Mineralogie', first published in 1891–2, ssed through several editions, the eleventh by P. Ramdohr in 1936.

Launay (Louis Alphonse Auguste de) [1860–1938], French geologist, s born in Paris on July 19, 1860, and died on June 30, 1938. Educated

at the École Polytechnique, in 1884 he entered the Corps des Mines, and worked on the geology and petrology of the crystalline rocks near Commentry, his first paper in 1888 being on the minerals from these rocks. This led to his long association with the Geological Survey of France of which he eventually, in 1930, became director. In 1889 he was appointed professor of applied geology in the École des Mines at Paris a post he held for 46 years. His work was on mineral-veins and ore-deposits, and he wrote many books on geology, mineral and thermal springs, on the gold mines of the Transvaal, diamond mines of the Cape, mineral resources of Africa and of Asia, &c. His 'Traité de métallogénie: gîtes minéraux et métallifères' appeared in three volumes in 1913. Of his forenames (also given as Louis Auguste Alphonse) he used only Louis, and curiously there was a Dutch mineralogist of the same name, Louis de Launay [1740–1805].

Compt. Rend. Acad. Sci. Paris, 1938, vol. 207, pp. 5–7.

Le Chatelier (Henry Louis) [1850–1936], French chemist, was born in Paris on October 8, 1850, and died at Miribel-les-Echelles, Isère, on September 17, 1936. Educated at the École Polytechnique and the École des Mines, he was first a mining engineer, returning to the École des Mines as professor of chemistry in 1877. After a transfer to the Collège de France, he succeeded H. Moissan in 1907 at the Sorbonne. He was distinguished as a physical chemist and metallographer. The Revue de Métallurgie was founded by him in 1904. His earlier work was on cements, to the study of which he was the first to apply petrographic methods. Quartz and clays were studied in their relation to ceramics and he wrote a book 'La silice et les silicates' (1914). Native silica-glass has been named lechatelierite.

C. H. Desch, Obituary Notices of Fellows of the Royal Society, 1938, vol. 2 pp. 251–259, with portrait; Journ. Chem. Soc. London, 1938, pp. 139–150, with portrait. Sir W. J. Pope, Nature, London, 1936, vol. 138, pp. 711–712. W. Kleber Zentr. Min., Abt. A, 1937, pp. 57–59. Compt. Rend. Acad. Sci. Paris, 1936, vol. 203 pp. 551–552. Revue de Métallurgie, special number, January 1937, 160 pp., with portraits and bibliography.

Lenk (Hans) [1863–1938], Emeritus Professor of Geology and Mineralogy in the University of Erlangen, was born May 17, 1863, at München and died on February 21, 1938, at Aschau near the Chiemsee in Bavaria. After graduating at Leipzig under Zirkel, two years were spent on a geological expedition to Mexico, and in 1889 he returned to Leipzig as assistant. In 1895 he was appointed to Erlangen, retiring in

933. His few published papers were petrographical and on the geology of exico. The set of forty coloured plates that appeared some thirty years go in popular books on minerals in English, Italian, and German were repared under his supervision from specimens in the Erlangen collection.

Zeits. Deutsch. Geol. Gesell., 1938, vol. 90, p. 173.

Louis (Henry) [1855–1939], Emeritus Professor of Mining in the niversity of Durham, was born in London on December 7, 1855, and ed at Newcastle-on-Tyne on February 22, 1939. From the City of ondon School he entered the Royal School of Mines with a Royal xhibition in 1873, and after taking the associateship in 1876 was ssistant for a year to J. Percy. In 1895 he was appointed professor of ining and lecturer in metallurgy in the Durham College of Science uter Armstrong College and now King's College) at Newcastle-on-Tyne, ssigning in 1923. Both before and after his term as professor he was a nsulting mining and metallurgical engineer, travelling extensively in parts of the world. He was the senior member of our Society, having en elected in 1879, and he contributed five papers to this Magazine 884–97) on occurrences of massive garnet in Catalonia, bismutite in ransvaal, ruby and sapphire in Siam, altaite in Burma, and on the ragenesis of gold. His earliest papers, in 1879, gave chemical analyses louisite (an incompletely determined mineral named after him) and kerite from Nova Scotia. He was the author of several text-books on ining and metallurgy, including a second edition of J. A. Phillips's re deposits' (1896) and 'Mineral deposits' (1934). Of his many mining ports, mostly confidential, one on the possibilities of gold-mining in erionethshire was published officially by the Mines Department in 30. He had been president of the Iron and Steel Institute, the Institu- n of Mining Engineers, and the Society of Chemical Industry.

Journ. Soc. Chem. Indust. London, 1931, Jubilee no., p. 84, with portrait. ining Journ. London, 1939, vol. 204, p. 136. J. A. S. Ritson, Nature, London, 939, vol. 143, p. 461.

Mellor (Joseph William) [1869–1938], distinguished for his work on ramic and refractory materials, was born at Huddersfield and was ken to New Zealand at the age of nine. After graduating at the niversity of Otago, he went, in 1899, with an 1851 Exhibition Scholar- ip to the University of Manchester. His connexion with the ceramic dustry at Stoke-on-Trent commenced in 1904, and he was the first rincipal of the North Staffordshire Technical College. Many papers

were written on the constitution of clays, and he proposed the names clayite and keramite. A monumental work is his 'Comprehensive treatise on theoretical and inorganic chemistry' (16 vols., 1922–37), in which are given a vast number of bibliographical references including many to mineralogical literature. He died on May 24, 1938.

Nature, London, 1938, vol. 142, pp. 281–282. Sir William Bragg, Proc. Roy. Soc. London, Ser. A, 1938, vol. 169, p. 7. A. T. Green, Obituary Notices of Fellows of the Royal Society, 1939, vol. 2, pp. 573–576, with portrait.

Phillips (Alexander Hamilton) [1866–1937], Professor of Mineralogy in Princeton University, New Jersey, was born at Lawrenceville near Princeton on May 15, 1866, and died at Princeton on January 20, 1937. All his life he was closely connected with Princeton. After graduating there in 1887 he was for 49 years on the teaching staff of the university, and in 1911–16 was Mayor of the borough. For some years he was instructor in biology and afterwards in analytical chemistry and mineralogy. He was appointed assistant professor of mineralogy in 1898 and full professor in 1903 (in succession to H. B. Cornwall), retiring in 1936, but acting as curator of minerals until the end. Of his few published papers, the earliest gave rock analyses, and later analyses have been published in posthumous papers. He described gageite as a new mineral, and zinc phosphates from British Columbia. His text-book 'Mineralogy', published in 1912, bears a close resemblance to Miers's well-known volume. He was chairman of the organizing committee for the foundation in 1919 of the Mineralogical Society of America, and its President in 1931. Since 1929 he was a member of our Society.

A. F. Buddington, Proc. Geol. Soc. Amer., 1937, for 1936, pp. 241–248, with portrait and bibliography; Amer. Min., 1937, vol. 22, pp. 1094–1098, with portrait.

Smith (Bernard) [1881–1936], Director of the Geological Survey and Museum of Great Britain, was born at Grantham on February 13, 1881, and died from cancer at Hove on August 19, 1936, at the early age of 55. It was only in October of the preceding year, shortly after the centenary celebration of the Geological Survey and the opening of the new Museum of Practical Geology, that he had been appointed director in succession to Sir John S. Flett; and a promising career was abruptly and cruelly ended. With a school scholarship from King Edward VI School at Grantham he entered Sidney Sussex College, Cambridge, in 1900, and in 1904 was appointed university demonstrator in geology. He joined the Geological Survey in 1906, and a portion of his work was in connexion

with mineral resources, particularly the iron ores and coal of Cumberland and gypsum deposits. He was elected a member of this Society in March 1936.

W. G. Fearnsides, Obituary Notices of Fellows of the Royal Society, 1938, vol. 2, pp. 239–249, with portrait. L. J. Wills, Quart. Journ. Geol. Soc. London, 1937, vol. 93, pp. cvii–cix. Nature, London, 1936, vol. 138, pp. 354–355.

Sollas (William Johnson) [1849–1936], Professor of Geology in the University of Oxford, a versatile and brilliant worker not only in all branches of geology, but also in zoology, mineralogy, and anthropology, was born in Birmingham on May 30, 1849, and died in Oxford on October 20, 1936. From the City of London School he passed to the Royal College of Chemistry, where his uncle, William Johnson, was registrar. In 1867 he gained a scholarship at the Royal School of Mines, and in 1870 a scholarship at St. John's College, Cambridge. After six years as Cambridge University extension lecturer in geology he was appointed curator of the Bristol Museum and Library, and in 1880 Professor of Geology and Zoology in University College, Bristol. From 1883 to 1887 he was Professor of Geology and Mineralogy in Trinity College, University of Dublin, and since then, for nearly fifty years, Professor at Oxford. During his time in Dublin he also acted as petrologist to the Geological Survey of Ireland, describing pleochroic haloes in the mica of the Wicklow granite, hybrid rocks from the mixing of granite and gabbro, zinnwaldite from the Mourne Mountains granite, the crystallography of riebeckite, &c. Descriptions of rocks were given in two volumes for the New Zealand survey, and he revised the section on mineralogy in the Admiralty Manual of scientific inquiry. The well-known diffusion column of heavy liquids for the determination of specific gravity is due to him, and he published a series of papers on the atomic structure of crystals. He was a member of our Society from 1897 to 1912.

A. S. Woodward and W. W. Watts, Obituary Notices of Fellows of the Royal Society, 1938, vol. 2, pp. 265–281, with portrait and bibliography. E. J. Garwood, Quart. Journ. Geol. Soc. London, 1937, vol. 93, pp. cix–cxv. J. S. Flett, Proc. Roy. Soc. Edinburgh, 1937, vol. 56 (for 1935–6), p. 283; Proc. Geol. Soc. America, 1938, for 1937, pp. 203–220, with portrait and bibliography. W. W. Watts, Nature, London, 1936, vol. 138, pp. 959–960; Proc. Geol. Assoc. London, 1937, vol. 48, pp. 110–112.

Štěrba-Böhm (Jan Stanislav) [1874–1938], Professor of inorganic and pharmaceutical Chemistry in the Charles University at Praha, was born at Sezemice in Bohemia on November 9, 1874, and died at Praha on

January 1, 1938. Graduating in pharmacy, he later studied the salts of the rare-earths cerium, scandium (which he extracted from wolframite and thortveitite), and germanium (extracted from argyrodite). He made chemical analyses of delorenzite, ultrabasite, thortveitite, and pisekite, new minerals described by other authors. He also studied the blue coloration of rock-salt.

J. H. Křepelka, Chemické Listy, 1938, vol. 32, pp. 41–42. S. Škramovský, Coll. Czech. Chem. Comm., 1938, vol. 10, pp. 1–7, with portrait. Nature, London, 1938, vol. 141, p. 149.

Stutzer (Otto) [1881–1936], Professor of fuel-geology in the Mining Academy of Freiberg, Saxony, was born at Bonn on May 20, 1881, and died at Freiberg on September 29, 1936. Studying at Königsberg, München, Tübingen, and Heidelberg, he graduated in 1904, and the next year was assistant to C. R. Beck at Freiberg. For his work in 1905–6 on the iron ores of Swedish Lapland, a long account of which was published in English, he was awarded the Carnegie medal of the Iron and Steel Institute in London. In 1908–9 he travelled in Canada, Alaska, and the United States, visiting Klondike with the Geological Survey of Canada; and in 1911–13 he led a geological expedition to Belgian Congo and Rhodesia. In 1921–26 he acted as geologist to an oil company and the government in Colombia, publishing a long series of papers on the geology and mineralogy of that country, including accounts of the emerald mines and of the problematical Colombian tektites. In addition to many papers on the ore deposits of several countries, he produced a valuable work of reference on non-metallic minerals 'Nicht-Erze' (6 vols., 1911–35), the sixth volume dealing with precious stones. Since his appointment in 1927 as director of the new Institut für Brennstoff-Geologie at Freiberg, his papers dealt with coal and oil. But on his last visit to America, as president of the Society of Economic Geologists, he visited in February 1936 the Meteor Crater in Arizona, and his last three papers, published after his death, were on meteorite craters.

R. Schreiter, Ber. Freiberg. Geol. Gesell., 1937, no. 16, pp. 6–9, with portrait and bibliography. J. T. Singewald, Bull. Amer. Assoc. Petroleum Geol., 1937, vol. 21, pp. 139–141, with portrait.

Sutton (John Richard) [1864–1937], distinguished as a meteorologist, was born at Wavendon, Buckinghamshire, on January 3, 1864, and died at Binfield, Berkshire, on October 11, 1937. He entered Sidney Sussex College at Cambridge in 1886 and graduated in the mathematical tripos in 1889, afterwards taking the Sc.D. degree in 1908. On leaving

Cambridge he joined the clerical staff of the diamond department of De Beers mines at Kimberley. In 1898 he was placed in charge of the company's new meteorological station at Kenilworth near Kimberley, from which he retired in 1928; and his scientific writings were mainly on meteorological subjects. But he also wrote several papers on diamond, one of which appeared in this Magazine (**19**–208), and his book 'Diamond, a descriptive treatise' appeared in 1928. These were mostly descriptive of curious formations and freak diamonds in his own collection with speculations as to their origin. He introduced the names framesite and stewartite for forms of impure diamond; and a supposed new mineral from Kimberley proved to be ferrosilicon.

Quart. Journ. Roy. Meteorological Soc., 1938, vol. 64, p. 127. Sidney Sussex College Annual, 1938, p. 18.

Tammann (Gustav Heinrich Johann Apollon) [1861–1938], Professor of inorganic Chemistry in the University of Göttingen, was born at Hamburg in Govt. St. Petersburg on May 28 (old style, May 16), 1861, and died at Göttingen on December 17, 1938. He graduated in 1885 at Dorpat = Yuriev (now Tartu in Estonia), where he was assistant and afterwards Professor of Chemistry. In 1903 he was appointed to Göttingen. Since 1904 he had acted as editor of the Zeitschrift für anorganische Chemie, to which journal he contributed, in collaboration with his pupils, a vast number of papers, covering a wide range of physical chemistry. Many of these related to the phenomena of crystallization, the growth and corrosion of crystals, mixed crystals, polymorphism, recrystallization in metals, &c. Two of his books on these subjects have been translated into English.

Zeits. Anorg. Chem., 1939, vol. 240, pp. 113–117, giving an extraordinary dialogue on his admission to the Hall of Spirits. Nature, London, 1939, vol. 143, pp. 291–292.

Alfred Edwin Howard Tutton (1864–1938), President of our Society in 1912–15, was well known for his refined measurements of crystals and his treatise on crystallography. He was born on August 22, 1864, in the Cheshire portion of Stockport, where his father was a Venetian blind manufacturer. At the age of thirteen he entered the office of the Town Clerk of Stockport, and later attended evening classes at the Stockport Mechanics Institute and also evening lectures on chemistry by Roscoe at Owens College, Manchester. On the results of the examinations of the Science and Art Department he gained in 1883 a Royal Exhibition to the Normal School (later Royal College) of Science at

South Kensington, at a time when Huxley, Frankland, Guthrie, and Judd were the professors. There he gained the prizes in chemistry and physics and the Murchison medal in geology, and was afterwards appointed demonstrator and lecturer in chemistry. During his first research work, with T. E. Thorpe in 1886–92, on the oxides of phosphorus, he was so attracted by the brilliant crystals of these compounds that he sought the aid of H. A. Miers in the British Museum for instruction in crystal measurement. After measuring crystals of some new organic compounds, he settled down to what may be regarded as his life's work in recording precise measurements for series of isomorphous salts, with the object of determining how far the various constants are affected by the replacement of different chemical elements. The largest of these series investigated in detail was that of the double sulphates and selenates, $R_2M(SO_4)_2.6H_2O$, where R = K, Rb, Cs, Am, Tl, and M = Mg, Zn, Fe, Ni, Co, Mn, Cu, Cd, which came to be known as 'Tutton's salts'. During the period 1893–1928 the various constants of no less than 77 of these salts were determined with the greatest possible accuracy, so affording valuable data for any future comparisons. He proved over and over again that all the characters of the rubidium salt are intermediate between those of the potassium and caesium salts. In connexion with this work elaborate pieces of apparatus were designed for cutting accurately orientated plates and prisms from crystals, producing a beam of monochromatic light, and for measuring the thermal expansion and elasticity constants of crystals. Since 1895 this enormous amount of careful work was done in his spare time in his private laboratory. In that year he was appointed an Inspector of Technical Schools and stationed successively in the Oxford, London, and Plymouth districts. During the period (1895–1905) at Oxford he was attached to New College, and took the degrees of B.Sc., D.Sc., and M.A. On his retirement from the Board of Education in 1924 his private laboratory was set up in Cambridge, and he lectured on crystallography in the university. A laborious piece of work, completed in 1931, with a modified form of his interferometer, was the evaluation of the Standard Yard in

A. E. H. Tutton (in 1936).

erms of the wave-lengths of light, which he undertook for the Standards Department of the Board of Trade. He wrote a history of this department and of the national standards which is to be published posthumously. He was an enthusiastic Alpine climber, visiting Switzerland almost every year, and he wrote a book 'Natural history of ice and snow' (1927) besides giving many popular lectures on this subject. Leaving Cambridge in 1931, his fine collection of instruments was transferred to the department of physics and crystallography in Manchester University, and he settled at Dallington in Sussex, where he died on July 14, 1938. For fifty years he was a Fellow of the Chemical Society; he joined the Mineralogical Society in 1891, and was early elected a Fellow of the Royal Society in 1899.

J. R. Partington, Nature, London, 1938, vol. 142, pp. 321–322. Sir William Bragg, Proc. Roy. Soc. London, Ser. A, 1938, vol. 169, p. 9. Obituary Notices of Fellows of the Royal Society, 1939, vol. 2, pp. 621–626, with portrait.

Ungemach (Henri Léon) [1879–1936], French crystallographer, was an Alsatian born at Strasbourg on September 10, 1879, and he died there on June 11, 1936. Educated at Strasbourg and the Polytechnic School at Zürich as a chemical engineer, he graduated at the University of Strassburg (Strasbourg) in 1907, with a thesis on the mineral veins in the Weilerthal (Val de Villé). After travels in Canada, United States, and Mexico, he exploited the silver mines of St. Sylvestre in the Val de Villé and prospected in Morocco, Algeria, Madagascar, and Abyssinia. On these expeditions he collected minerals as well as other natural history materials. After his death the bulk of his mineral collection was acquired by the University of Liége. This collection had supplied him with material for careful goniometric measurements, and he published a series of papers on the crystallography of various minerals, recording many new crystal-forms. Discussing the sequence of face-indices along zones in relation to lattice structure, he proposed new orientations for the crystals of some minerals. In 1932 he was attached to the mineralogical

H. Ungemach.

laboratory of the University of Strasbourg, with the duty of rearranging the collection and revising the catalogue of minerals. There he came across a series of sulphate minerals from Chile, amongst which he discovered and described the new species amarillite, lapparentite, leucoglaucite, and paracoquimbite. For the regular intergrowth of dimorphous substances which show some crystallographic relationship, such as coquimbite and paracoquimbite and the different types of carborundum, he introduced the term syntaxy; and such substances were called polytypes. Two other sulphate minerals from Chile have, since his death, been named ungemachite and clino-ungemachite. Since 1919 he was the foreign secretary of the French Mineralogical Society.

R. Weil, Bulletin de l'Association amicale des Ingénieurs-Chimistes diplomés de l'Institut de Chimie de Strasbourg, June 1937. R. Hocart, Bull. Soc. Franç. Min., 1938, vol. 61, pp. 142–173, with portrait and bibliography.

Wallerant (Frédéric Félix Auguste) [1858–1936], French crystallographer and an honorary member of this Society since 1913, was born at Trith-Saint-Léger near Valenciennes on July 25, 1858, and died in Paris on July 11, 1936. Educated at the Lycée in Marseille and the École normale supérieure in Paris, he was successively assistant in Marseille, Professor of Geology and Mineralogy in the University of Rennes, and Maître de conférences in geology at the École normale. In 1903 he was appointed Professor of Mineralogy in the University of Paris, in succession to P. G. Hautefeuille, retiring in 1933 with the title of honorary professor. His first papers in 1888 were petrographical, and his doctoral thesis in 1889 was on the geology of Maures and Estérel. He also did some few sheets of the geological map of France. But his main work was on the symmetry and lattice structure of crystals in relation to twinning, regular grouping of crystals, so-called optical anomalies, and the problems of isomorphism and polymorphism. His volume 'Cristallographie' (1908) dealing with these matters was really the completion of E. Mallard's 'Traité de cristallographie' (1879–84), the third volume of which was never published. He also gave a 'Traité de minéralogie' in 1891. He was elected a member of the Paris Academy of Sciences in 1907, and was President of the French Mineralogical Society in 1905 and 1916.

Compt. Rend. Acad. Sci. Paris, 1936, vol. 203, pp. 137-139.

The adinoles of Dinas Head, Cornwall.

(With Plate XI.)

By S. O. Agrell, B.A., F.G.S.

Department of Mineralogy and Petrology, University of Cambridge.

[Read November 3, 1938; communicated by Prof. C. E. Tilley, F.R.S.]

Contents.

	PAGE		PAGE
I. Introduction . .	305	VII. Completely metasomatized rocks—Adinoles . .	315
II. General geological relations	306	VIII. The chemical constitution and origin of adinoles	327
III. The igneous rocks. .	307	IX. Publications to which reference is made . . .	337
IV. The sedimentary rocks .	311		
V. Rocks showing effects due to pure thermal metamorphism	312		
VI. Rocks showing localized metasomatism—Spilosites .	314		

I. Introduction.

DINAS Head is a small promontory adjoining Trevose Head, some five miles west of Padstow on the north coast of Cornwall. Petrographical attention was first drawn to it by Howard Fox, who in 1894 [5], noted the development of albite-rich rocks between greenstone and slate, and he concluded that the rock was an adinole. He also noted the peculiar spherulitic development of albite giving some rocks an igneous appearance, but, on account of the fine banding preserved in these rocks, he concluded that they were metasomatized sediments. This conclusion was subsequently supported by McMahon and Hutchings [13]. The Memoir of the Geological Survey of the Padstow and Camelford district [17] agrees with Fox as to the origin of the adinole, and points out the exceptional thickness of its development when compared with other greenstone-slate contacts.

The latest publication is that of Dewey [4], who showed that the composition of the slate into which the greenstones are intruded affects in some measure the products of metamorphism. Namely, that purple and red slates develop spots, but are not adinolized; green slates develop spots and poor adinoles; grey and black slates do not develop spots, but are strongly adinolized. That is, those sediments poor in Fe_2O_3 are altered to adinoles, and those rich in Fe_2O_3 to spotted slates. He suggests

that the material was added as albite-rich liquors carrying magnetite, and that these liquors were derived from the albite-dolerite intrusion; and further, that those intrusions which, in general, have Fe_2O_3:FeO greater than three to one, give rise to adinoles at their contact with slates.

The present study was undertaken in order to investigate the chemistry of adinolization more closely and to discover the reason for the development of such an exceptional thickness of adinole at Dinas Head.

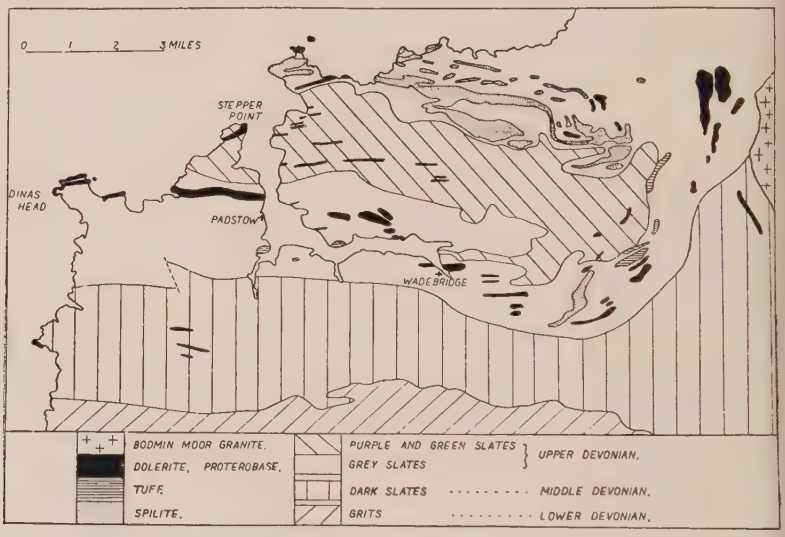


Fig. 1. Geological sketch-map of the St. Mabyn syncline, based on data taken from publications of H.M. Geological Survey.

II. General Geological Relations.

Dinas Head is situated at the seaward end of the south limb of the St. Mabyn syncline (fig. 1) and is composed of a series of dark slates, limestones, and cherts of Upper Devonian age into which, prior to the imposition of cleavage on the sediments, there has been intruded a sill of albite-dolerite. This intrusion is at about the same stratigraphical level as the spilites and tuffs on the north side of the syncline, and, chemically, is closely allied to them.

A series of albite-rich rocks interpreted as adinoles occurs between the dolerite and the unaltered sediments. Being on the line of movement which runs from Trevose Head to Tintagel [8], all the rocks have been

rongly folded and faulted during the Armorican orogeny, and as a esult the detailed relations are obscured by the folding of the adinole to the slates and by its being torn away from the contact with the neous rock, and no one band of sediment can be traced with certainty to its metasomatized equivalent.

III. The Igneous Rocks.

The intrusive rock is a typical 'greenstone' and the available exposures show that it has the form of the irregular upper surface of what possibly a thick sill, or the upper surface of a plug-like mass from which sills develop, for it sends several distinct tongues into the sediments. These sediments and associated sills may be seen best on the south side of the headland and dip about 20° to north. They are upfaulted again on the north of the headland, and, although the relations here are more obscure, a tongue of igneous rock branching from the main mass can be observed. Where Dinas Head joins the main part of Trevose Head, the upper part of the igneous rock is at sea-level. Above Booking Cove a wide dike commences striking across Trevose Head. The general relations of the igneous rock and the altered and unaltered sediments are shown on the map in fig. 2.

1. *Petrography of the albite-dolerite.*—The bulk of the intrusive rock at Dinas Head is albite-dolerite which appears as a coarsely mottled, dull, dark-green rock with paler patches, and which weathers with a rusty crust where out of the influence of the sea waves. The greater part of the rock is strongly carbonated and chloritized, and little of the original textures can be seen (fig. 4 c). In less altered specimens, pseudomorphs after ophitic pyroxene are preserved and correspond to the paler patches in the rock.

Albite of refractive index (γ 1·537–1·541 in different specimens), corresponding to a composition $Ab_{100}An_0$–$Ab_{92}An_8$, occurs as laths penetrating the pseudomorphs after ophitic pyroxene and as laths forming the groundmass of the rock. In all specimens zoning is absent and no traces of a more basic plagioclase are observable. The albite is usually twinned on the albite law and in the fresher rocks is of a limpid appearance and has, as inclusions, small linearly arranged granules of carbonate and flakes of white mica.

Pyroxene is not found in the typical dolerite, but pseudomorphs after ophitic plates occur of a fibrous mineral of the bowlingite group, whose optical properties are α 1·570 pale brown to nearly colourless, γ 1·605 dull brown, $\gamma - \alpha$ 0·035, 2V very small, sensibly uniaxial, negative.

Fibres of the mineral show positive elongation and straight extinction. Calcite may occur in a granular form associated with the bowlingite.

Fig. 2. Geological sketch-map of Dinas Head to show the distribution of the dolerite, slates, and adinoles.

Chlorite is usually very fine grained and belongs to the diabantite-aphrosiderite group [16, p. 280], being optically negative with β 1·625–1·643. It forms the matrix in which all the other minerals are set, and occasionally is seen as pseudomorphs after pyroxene and (?) biotite, in which case it contains small grains of sphene or anatase.

Serpentine in the form of small pools of a fine-mesh serpentine is common in most of these rocks, but in no case does it appear to be a pseudomorph. Prehnite occurs occasionally as sheaf-like aggregates of crystals. A ferriferous calcite sometimes occurs along with the bowlingite

placing the pyroxene, and a colourless granular calcite occurs abun-
ıntly throughout most of the rocks and in small stringers.
Ilmenite occurs as skeletal plates altered to leucoxene, which may
enerally be recognized as sphene, although anatase is developed occa-
ɔnally. Pyrite and needles of apatite are found in very small amounts.

Fig. 3. Interbanded spilosite and adinole from the west side of Dinas Head, Cornwall.

No pegmatitic facies of this dolerite has been observed, nor have
·oliths of albitized sediment been found. The varieties of dolerite
ır the contact are usually so chloritized that the original minerals
ınot be identified, but occasionally on the south side of Dinas Head
hin band of chilled margin can be seen. In thin sections this is seen
be made up of over 90 % of albite which occurs as thin laths about
ım. in length arranged in a criss-cross manner, giving the rock a
ven appearance when seen between crossed nicols (fig. 4 B). Chlorite
s the interstices, and accessory minerals are carbonate, sphene, ana-
e, apatite, and ilmenite.

2. *Petrography of the pyroxene-bearing albite-dolerite.*—This rock occurs
y in one rocky knob on the south side of Dinas Head. On the fresh
face it has a dark greeny-black lustrous appearance. Pyroxene is a
ɔurless pigeonite and occurs as relicts of ophitic plates (fig. 4 A).

Hornblende is a fibrous, pale-green actinolite with γ 1·65 and $\gamma : c = 16°$. It replaces the pyroxene and is itself replaced in part by a pale biotite with γ 1·62, $\alpha = \beta$ pale straw, γ pale foxy-red. These replaced ophitic plates are penetrated by the laths of albite, which, together with much granular calcite, form the groundmass. Ilmenite occurs as grains and skeletal plates surrounded by a broad rim of sphene.

Fig. 4 A. Pyroxene-albite-dolerite. ×27.
Fig. 4 B. Marginal modification of dolerite. ×27.
Fig. 4 C. Normal albite-dolerite. ×27.

It is possible that this rock has been less subject to autolytic alteration than has the preponderant type. Along joints the ferromagnesian minerals are usually prehnitized and much carbonate and sphene have developed. It is in these types that the albite sometimes shows the fine pepper-and-salt texture of interlocking granules that is so characteristic of the adinoles.

3. *Petrography of the segregation veins.*—These veins are often present cutting the dolerite close to the contact with adinole, but can seldom be traced any distance into the latter. They are sharp walled, about 10 cm. thick, and distinctly banded. Albite as grains 4 mm. in diameter makes up the bulk of the rock and is marginally intergrown with dolomite and ankerite. Chlorite is usually also present. The ankerite has

1·705, corresponding to the composition $CaMg(CO_3)_2$ 70 %, $CaFe(CO_3)_2$ 0 %.

4. *Chemical composition of the albite-dolerites.*—Analyses of the normal albite-dolerite (1) and of the pyroxene-bearing type (2) are given in Table I and agree fairly closely, especially when account is taken of the strong autolytic modification to which both rocks have been subjected. Norms calculated on a CO_2-free basis show that in the case of the normal albite-dolerite there would not be enough lime to form normative calcite. In the mode, FeO replaces CaO in the carbonate associated with bowlingite.

Table I. Chemical analyses of albite-dolerites and slates.

	1.	2.	A.	3.	4.	5.
SiO_2	46·90	45·10	46·73	56·97	60·36	64·70
TiO_2	1·58	1·26	2·74	0·62	0·56	0·58
Al_2O_3	14·92	16·04	18·73	22·36	18·25	20·77
Fe_2O_3	1·63	1·67	0·00	0·63	0·60	0·89
FeO	9·72	8·26	10·14	5·16	6·94	1·86
MnO	0·16	0·17	0·37	0·00	0·04	trace
MgO	6·58	7·96	3·56	2·84	3·24	1·52
CaO	4·15	7·60	8·62	0·60	1·12	trace
Na_2O	3·79	3·61	3·54	0·51	0·12	0·31
K_2O	0·46	0·48	0·88	4·57	3·14	4·81
H_2O+	4·92	4·68	3·31	4·32	4·26	3·42
H_2O-	0·70	0·80	0·35	0·60	0·70	0·65
P_2O_5	0·13	0·10	0·37	0·09	0·09	0·12
CO_2	4·38	2·22	0·58	0·00	0·48	trace
... ...	—	—	—	0·88	0·00	0·34
Total	100·02	99·95	99·97	100·15	99·90	99·97
Sp. gr.	—	—	—	2·81	2·66	2·73

1. Albite-dolerite, Dinas Head. Analyst, W. H. Herdsman.
2. Pyroxene-albite-dolerite, Dinas Head. Analyst, W. H. Herdsman.
A. Albite-diabase, Trusham station quarry, Devonshire. Analyst, E. G. Radley [7]. Also FeS_2 0·05.
3. Black carbonaceous slate with small chlorite-rich spots, Dinas Head. Analyst, W. H. Herdsman. B_2O_3 0·00.
4. Dull grey-green spotted slate, Dinas Head. Analyst, W. H. Herdsman. B_2O_3 0·00.
5. Black fissile spilosite, Dinas Head. Analyst, W. H. Herdsman. B_2O_3 0·00.

IV. The Sedimentary Rocks.

The unaltered sediments are predominantly dark slates and call for little description. Bands of crinoidal and unfossiliferous sheared limestone, sometimes associated with chert, occur as a horizon in brown-black calcareous shales. At the end of the headland these are replaced by green-black slates showing minute puckering.

A band of coarse schalstein occurs just above high-water mark on the north side of the headland. It is two or three feet thick and can be traced only for a few yards. It is very probably a continuation of a similar band occurring between tide marks below the lighthouse on Trevose Head. This is the only rock which has been recognized as definitely showing primary pyroclastic features on Dinas Head. No recognizable tuffs, keratophyric, and hence like adinoles, in composition, have been found to explain the great thickness of the adinole.

V. Rocks showing Effects due to Pure Thermal Metamorphism.

In a general way these rocks always lie between the unaltered sediments and the spilosites and adinoles. The first change visible is always a development of spots which may be one of the three following types:

(*a*) In black slates, small chlorite-rich spots, lenticular in shape and about 0·5 mm. long, occur in a groundmass of fine sericite with a little chlorite, in which clastic grains are still visible. Films of carbonaceous material are abundant in the sericite, and around the chlorite spots they have been pushed apart like the eyelids around an eye. Fig. 5 A shows this blepharitic structure which is a common feature in spotted slates [18, pp. 64–66]. The chlorite has γ 1·623, $\gamma - \alpha$ 0·002 approx., is optically negative, olive in colour, and hence a diabantite. It is thought that these spots are due merely to a local rearrangement of material, the bulk composition of the rock being unchanged. The chemical composition is given under (3) in table I and shows no unusual features.

(*b*) In black slates there are sometimes developed much larger spots up to 3 mm. in diameter and elongated in the fissility planes. They are marked by a concentration of chlorite similar to the above and are fringed with carbonate, now represented by limonite which sends rays into the cores of the spots. The groundmass is made up of fine sericitic white mica, some chlorite, and disperse carbonaceous films. Minute granules of leucoxene occur throughout. Clastic quartz occurs both in the groundmass and in the spots.

(*c*) In dull green-black slates occur compound spots, possibly allied to those described in (*b*). These are 2–3 mm. long and are elongated in the fissility planes (fig. 5 B). They show a chevron structure. A thin outer zone of chlorite delineates the spot, and from this irregular rays of chlorite, with or without fine granular calcite, branch towards the centre of the spot. The chlorite has γ 1·612, $\gamma - \alpha$ 0·001 approx., and is optically positive or negative, thus corresponding to a magnesium-rich diabantite.

etween these rays, and making the core of the spot, there occurs un-
iented white mica (γ 1·588). A considerable amount of quartz may be
esent in the spot, generally associated with the chlorite rays, but some-
mes with the sericite, and occurs as fine interlocking grains compared
ith the angular grains associated with the sericite of the groundmass.
he groundmass is sericite with a little chlorite and ores, and its analysis
, table I) shows the characters typical of an argillaceous rock. The
olour change from black to green is accompanied by an increase in the
tio of FeO to Fe_2O_3.

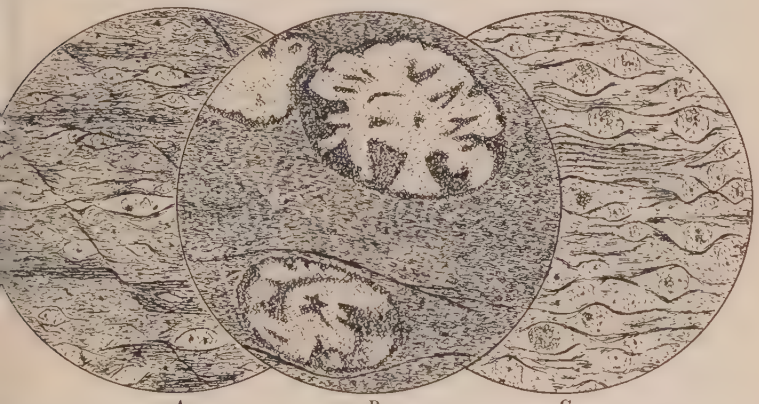


Fig. 5 A. Black carbonaceous slate. A sericitic groundmass with carbonaceous
ms showing blepharitic structure around chloritic spots. ×20.

Fig. 5 B. Dull green spotted slate. A sericite-chlorite groundmass with spots com-
osed of a margin of chlorite with a little calcite, sending rays into a sericitic
re. ×8.

Fig. 5 C. Black slaty spilosite. A sericitic groundmass with films of carbonaceous
aterial showing blepharitic structure around round spots composed mainly of
uartz and a little chlorite. ×20.

These spots have not the simple structures of spots due to localized
oncentration of material, and it is evident that very definite reactions
ust have taken place to produce, for example, the quartz that is
esent. Possibly they represent incipient cordierite, just as those with
gular chevrons have, at many localities, including Stepper Point
7, p. 49] and Trusham [18, p. 65], been taken to represent incipient
iastolite. The chemical composition agrees closely with that of the
ornfelses of group I of Goldschmidt, so that it is not unreasonable to
pect some such reaction to have taken place in the early stages of
etamorphism.

VI. Rocks showing Localized Metasomatism—Spilosites.

These occur between the slates and the adinoles and are somewhat sporadic in development. Spilosite and adinole may even be seen banded together.

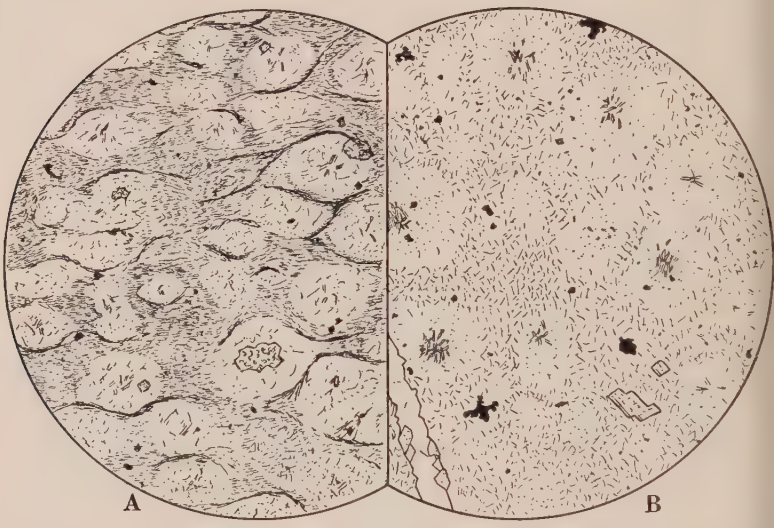


Fig. 6 A. Spilosite. Spots of fine-grained albite with a little chlorite, colourless tourmaline, and anatase are set in a groundmass of sericite with thin carbonaceous films. ×27.

Fig. 6 B. Spilositic adinole. Coarser areas of albite with colourless tourmaline are set in a very fine-grained groundmass of the same mineralogical composition with mossy aggregates of leucoxene and occasional small rhombs of ankerite, and cut by a quartz vein showing marginal recrystallization of albite. ×27.

An example analysed (5, table I) is, in hand-specimen, a black slaty spilosite with spots of pin-point size. These spots are composed of quartz with a little chlorite and leucoxene and are set in a groundmass of fine white sericitic mica with thin carbonaceous films forming typical blepharitic structures around the quartz spots. Leucoxene occurs as very fine granules in the groundmass (fig. 5 c). The analysis of the rock shows that it could be equally well regarded as a normal spotted slate, for there is nothing, except the high silica percentage, which might be attributed to the metasomatism.

Coarser types occur in which the material in the spots can be definitely recognized as albite. These rocks have small spots about 1 mm. in

ameter, and are composed of interlocking crystals of albite with which associated tabular crystals of anatase or granular leucoxene and edles of a colourless tourmaline of the dravite-uvite series (average 1·635) [11, p. 221]. The groundmass is composed of sericitic white ca without any tourmaline (fig. 6 A). It is of interest to note here that x [5, pp. 705, 715] recorded the presence of minute crystals of xagonal outline, which he tentatively referred to wollastonite in some es, to tridymite in others. It is possible that these are small needles ourmaline comparable with those just described. This rock forms the k bands in fig. 3 and has been analysed (6, table II), and may be npared with B, a spilosite from the Harz analysed by Kayser [10, 139].

This coarser type can be seen to pass into what may be termed a lositic adinole, by replacement of the groundmass sericite by very e-grained albite and quartz accompanied by minute tourmaline dles, granules of leucoxene, and small rhombs of ankerite. The ially metasomatized spots are seen as coarser areas about 1 mm. in meter evenly scattered through the rock and composed of the same erals as the later-formed fine-grained base (fig. 6 B). The analysis iven under (7) in table II. This type of adinole forms the white bands ig. 3, and the change from spilosite to spilositic adinole corresponds he original banding of the rock. As these two rocks, so closely inter-ded, must have been subject to the same metasomatic fluids, it ows that the composition of the original sediment had a very strong trol over the ease with which it could be adinolized.

VII. Completely Metasomatized Rocks—Adinoles.

The adinoles are of a simple mineralogical composition being essen-ly albite and quartz. Associated with these, there commonly occur rite, calcite, ankerite, leucoxene, and a colourless tourmaline of the vite-uvite series. Zoisite, rutile, graphite, and prehnite occur in very ll amounts.

n the field, adinoles are characteristically banded like a normal series ediments. They exhibit a variety of textures and structures, some hich can be seen developing, others of which present no clue as to r origin. According to these, the rocks may be divided into the wing groups:

Normal adinoles—very fine-grained with albite, quartz, and calcite. They may be rich in carbonate.

2. *Pseudomorph-bearing adinoles*—in which the pseudomorphs are of three types:
   (*a*) quartz-chlorite pseudomorphs after andalusite;
   (*b*) carbonate-chlorite pseudomorphs after andalusite;
   (*c*) chlorite-rich types with occasional pseudomorphs after andalusite and many replacements of initial spotting or of incipient andalusite or cordierite.
3. *Carbonate-rich adinoles*—characterized by globular masses of ankerite, up to 2 cm. in diameter.
4. *Spherulitic adinoles*—characterized by spherulitic groups of albite.
5. *Sheared adinoles.*

It has been possible to trace the changes from slate into adinole only in the normal adinoles. There are, however, features in the adinoles of the other groups which provide clues as to the stages of their development.

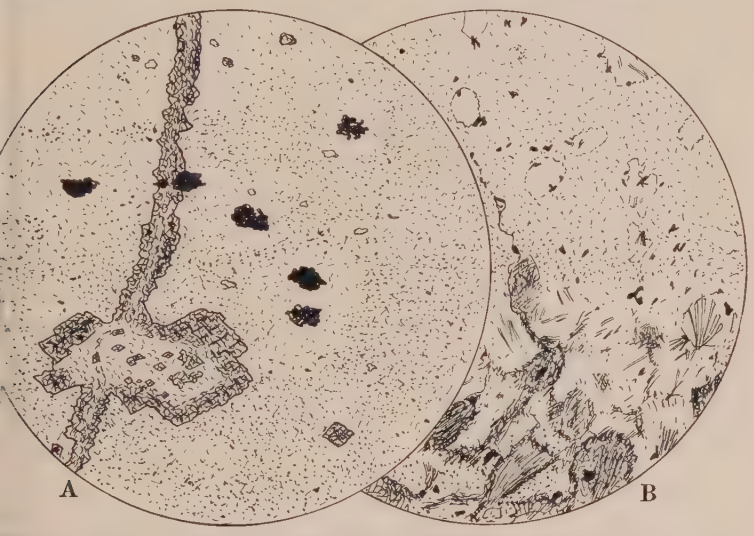
1. *Normal adinoles.*

These are built up essentially of albite and quartz and appear as hard, white-weathering rocks with a grey-white cherty appearance on the fresh surface. They are distinctly bedded and may be interbanded with other types of adinole. A very fine banding may also run through them, and is best seen on weathered surfaces or in thin sections [7, fig. 57 A]. Jointing is prominent and is accentuated by very thin quartz veins which may fill the joints, giving a somewhat brecciated appearance to the rock.

The albite and quartz occur as minute, sutured, interlocking grains too fine to allow detailed optical tests. The average refractive index is 1·537±, so that the greater part is albite. Analysis also shows that albite makes from 65 to 85% of the rock, and that it never has more than 5% of anorthite. Set in this groundmass coarser patches of albite of one of two types may occur. (*a*) The patches are rounded or irregular areas about 0·25 mm. in diameter. They are made up of coarse albite and chlorite and merge rapidly into the groundmass. These are relicts of the first-albitized spots. (*b*) Rounded pools about 0·2 mm. in diameter are made up of one or two crystals of albite with a faint brown turbidity, and have a sharp though crenulate contact with the groundmass. Quartz may also occur in the same manner. These may also represent the first-albitized spots or may be a later recrystallization phenomenon.

Chlorite occurs as minute flakes throughout the rock; as it increases in amount the rocks pass into adinoles of group 2 *c*. Carbonaceous films occur in some specimens and serve to accentuate the original banding

, fig. 57 A]. Leucoxene may occur as small mossy aggregates evenly attered through the rock and sometimes banded. In places they have een concentrated into larger aggregates leaving an impoverished zone ound them. This seems commonest near a contact with the dolerite g. 7 A). Minute needles of colourless dravite occur in small amount many of the adinoles. Zoisite may occur as isolated granules.



IG. 7 A. Normal adinole. A very finely crystalline base of albite and quartz th flakes of chlorite and granules of leucoxene, the latter sometimes segregated, ut and replaced by an ankerite vein. ×27.

IG. 7 B. Tourmaline-bearing adinole. Pools of quartz with needles of rutile and rmaline, set in fine-grained albite, and merging into a felted mass of tourmaline edles set in albite. ×27.

Of carbonates, both calcite and ankerite occur. The latter has 70% lomite and tends to be idiomorphic. These carbonates may form iso- ced crystals, patches, or larger nodules and bands showing intermediate ages to group 3 adinoles. The ankerite is usually connected with the artz-ankerite veins and can be seen replacing the adinole (fig. 7 A). ne calcite seems to be more in the bands and nodules, and it is possible at it has been derived from the original sediment. Some veins, which e generally earlier than those with ankerite, carry quartz alone, and e albite from the adinole forming the margin has recrystallized as little iomorphic crystals directed towards the centre of the vein.

An analysis of a normal adinole with no dravite and a little ankerite,

such as is shown in fig. 7 A, is given under (8) in table II, and agrees closely with the spilositic adinole (7) and the one (C) quoted by Fox [5].

In adinoles carrying a large amount of colourless tourmaline, usually an intermediate member of the dravite-uvite series with ω 1·635 and ϵ 1·615 on the average, the tourmaline occurs in several distinct ways. (*a*) As tufts of needles concentrated in certain bands of an otherwise very fine-grained and even-textured adinole. (*b*) As tufts radiating from small elongated pools of coarser albite and quartz into a normal fine-grained adinole in which occasionally a little zoisite is present. (*c*) As needles in albite forming coarser bands 2 mm. wide with carbonate of a later stage of metasomatism, alternating with fine-grained adinole. (*d*) In a peculiar adinole showing rounded and elongated patches from $1\frac{1}{4}$ inch in length, composed of normal albite and quartz as fine-sutured grains with pools of coarser albite or quartz, several often in optical continuity. At the margins of these, needles of sagenitic rutile occur, and penetrating the pools are needles of tourmaline. This composite core is surrounded by a zone of coarser-grained material in which quartz predominates over albite and which contains many bunches of tourmaline needles. The space between the above patches is filled with very fine-grained albite full of felted bunches of tourmaline needles and granular leucoxene (fig. 7 B).

2. *Pseudomorph-bearing adinoles.*

These are found only on the south side of Dinas Head at distances less than twenty feet from any contact with the albite-dolerite. They have a white-weathering base like a normal adinole, but set in this, and generally weathering out from it, are pseudomorphs of a mineral which has the habit of andalusite (fig. 13, pl. XI). In different bands of adinole these pseudomorphs vary from $\frac{1}{4}$ to $1\frac{1}{2}$ inches in length, and may be so abundant that a weathered surface is covered by an intergrown mat of them. In the actual outcrop they are a means of indicating sedimentary bedding, for there are bands rich in pseudomorphs and bands comparatively free from them.

Specimens of pseudomorphs were detached for goniometric measurement, but even when glass slivers were cemented on to the faces, no exact measurements could be obtained. This was due to the rough nature of the faces and to the long groove which runs down them, giving a rather chiastolite-like form. Although the pseudomorphs are not definitely proved to be after andalusite it is highly probable that they are, and with this reservation in mind they are referred to as andalusite

seudomorphs in the sequel. In none of these types has tourmaline been etected in any significant amount.

(*a*) *Types with quartz-chlorite-rich pseudomorphs* (fig. 8 A).—The seudomorphs are made up of coarse, slightly elongated grains of quartz, ften full of dusty inclusions of chlorite and ores. A very subordinate mount of granular leucoxene may occur in small patches. The inter- ices of the quartz grains are filled with a very fine-grained, pale yellow-

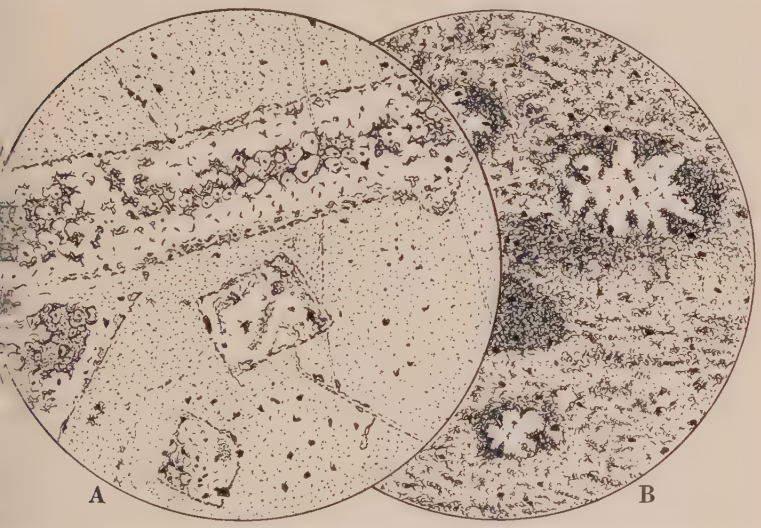


FIG. 8 A. Adinole with quartz-chlorite pseudomorphs after 'andalusite', set in a ry fine-grained matrix of albite and quartz with granules of leucoxene. ×5.

FIG. 8 B. Chlorite-rich adinole. A base of fine-grained albite and chlorite with dorite-rich patches and rounded areas of coarser albite with rays of chlorite. ranules of fine leucoxene occur throughout. ×27.

een chlorite, which has positive elongation, negative sign, bire- ngence greater than 0·004, and the average refractive index varies in fferent specimens from 1·61 to 1·625, so that this chlorite is also a ember of the diabantite-aphrosiderite group. The junction between oundmass and pseudomorph is always very sharp and the change of ain size is sudden.

Carbonate also may be present in small amounts. It is found replacing, part, the groundmass adinole at the margins of the pseudomorphs and now represented by limonitic rhombs.

As in the normal adinoles, the groundmass is a very fine-grained ggregate of albite and quartz, with a little chlorite, leucoxene, and

carbonate; it occasionally shows a very fine banding, but no coarser patches or pools of albite are present.

(*b*) *Types with carbonate and chlorite-rich pseudomorphs.*—These pseudomorphs are made of coarse-grained ferriferous calcite as sutured grains, a chlorite similar to that in the quartz-rich pseudomorphs, and minor amounts of albite and quartz. On the weathered surface these pseudomorphs are rod-like and do not show the andalusite habit but are more irregular. This may be due to their replacing a different mineral, to the greater ease with which they are weathered, or to the reaction of the carbonate with the groundmass with the resulting obliteration of any crystal boundaries.

(*c*) *Chlorite-rich adinoles with chlorite pseudomorphs.*—These rocks occur only on the south side of Dinas Head associated with the other pseudomorph-bearing adinoles. The bands in which they occur can sometimes be traced laterally into bands containing quartz and chlorite-rich pseudomorphs, sometimes into bands containing the carbonate-rich type of pseudomorph. The relative amounts of albite and chlorite vary. On the whole, albite increases towards the main igneous contact. Some of the rocks of this type weather more readily than others.

The less altered type is a grey-green splintery rock, weathering with a greeny-white colour and covered with pinhead excrescences. It is a chlorite-albite-quartz-rock. The chlorite is a pale olive diabantite, γ 1·62, optically negative, birefringence greater than 0·004, and is the predominant constituent of the rock. It occurs with subordinate albite, concentrated in rounded patches in bands of very fine grain-size which merge into the groundmass and also scattered among the very fine-grained interlocking albite and quartz of the groundmass. Enclosed in this fine-grained albite and quartz are coarser albite and quartz areas with interstitial chlorite which correspond to the pinheads on the weathered surface. These are about 1 mm. across and either rounded or rectangular in form. In the former the chlorite may form irregular rays; in the latter the rectangular outline is seen in ordinary light only when the source is cut down to a pinpoint by a diaphragm. They may be pseudomorphs after incipient andalusite or cordierite or the first-albitized spots of the original sediment (fig. 8 B).

The more altered type is pinky-white on the fresh surface and has occasional large chlorite patches which weather green in a groundmass which weathers white. This type is exactly the same mineralogically as the less altered type described above, and contains similar coarse albite patches, but the chlorite-rich areas are fewer. The groundmass is of very

e albite and quartz in interlocking grains and contains little chlorite; ıcoxene is gathered into larger patches. Albite crystals as irregular ains coarser than usual may be scattered evenly throughout the rock, rresponding to those in normal adinoles.

In these types, simple banding marked by relative concentration of dorite and albite is common. Also, on the weathered surface the rock seen to be made up of small lenticles, 5–10 cm. in length and packed gether rather like a small-scale current bedding, but differing in the rt that the banding within each adjacent lenticle usually dips in oppo- e directions. This has been observed in one or two other specimens, oecially of the carbonate-rich adinoles, but the structure cannot be tched with any known examples.

Pseudomorphs after andalusite similar to those in (*a*) and (*b*) are presented by angular areas of chlorite and calcite, with a little albite, artz, white mica, and leucoxene; these being confined to occasional nds. The chlorite is a bright yellow-green with γ 1·625, and bire- gence greater than 0·004, is optically negative, and again one of the ne series as has been described in the normal adinoles. It is very fine- ined and sends stringers into the carbonate which occurs in it as nded or irregular pools. Generally the chlorite lies between the bonate and the groundmass adinole.

3. *Carbonate-rich adinoles.*

Calcite or ankerite occur in most of the adinoles, either as isolated stals associated with late veining or as bands which may represent e-rich bands in the sediments. Certain adinoles, however, have bonates showing a very peculiar structure which warrants their being in a class by themselves. These are found below the adinoles with andalusite pseudomorphs on the south side of Dinas Head, between m and the top of the igneous intrusion. They are characterized by bular masses of ankerite ($CaMg(CO_3)_2$ 73%) up to 1·5 cm. in diameter, ich are evenly distributed throughout the adinole. The four feet of nole adjacent to the contact is free from carbonate, and is generally owed by three or four feet where the globular masses are solid and s upwards (in about ten feet) into a type with concentric structures . 14, pl. xi). These pass gradually into the pseudomorph-bearing noles.

n the hand-specimen, the core of ankerite seems sharply separated n an outer shell of ankerite by a distinct shell, 1–2 mm. wide, of very -grained quartz and albite. The outer shell of ankerite, 2–4 mm. in

thickness, may have a sharp or a transitional outer margin into the normal adinole in which the globular masses are set. The adinole weathers white with many small pinhead brown specks representing ankerite scattered in the groundmass.

In slice, the core of ankerite is seen to be composed of only a few crystal units, with an irregular outer margin. The intermediate zone of adinole is often difficult to distinguish, as it carries much carbonate. The outermost zone has the same composition as the inner, and has a comparatively sharp inner margin and a very irregular outer one which occasionally fingers out into bands replacing the main mass of the adinole, relicts of which can be seen within the ankerite. Apart from the above carbonates, the rock is composed of albite and quartz as very fine interlocking grains, in which are set sporadic albite grains up to 0·1 mm. in diameter and with sutured margins. Traces of banding due to minute chlorite flakes are occasionally seen and small patches of ankerite with irregular rhombohedral outlines are scattered all through, as also are small mossy patches of leucoxene.

Between the adinoles with pseudomorphs and the adinoles with globules of carbonate, a band occurs which, on the white-weathered surface has many rounded and sub-angular excrescences, each about 2 mm. long. These give the rock the appearance of a fine-grained porphyritic igneous rock; but in slice, the majority of these excrescences are seen to have exactly the same structures as the replacements in the chlorite-rich adinoles with the andalusite pseudomorphs, namely, rounded form, grain-size coarser than that in the groundmass, and irregular rays of chlorite running into the centre. When the illumination is cut down to a pinpoint, some show rectangular forms, but this outline is not defined by the change in grain-size between the coarser patches and the groundmass.

Carbonate-rich adinoles, rather weathered, occur at the top of the cliff on the south side of the neck adjoining Dinas Head to the mainland. A partial analysis showed Na_2O 5·96, K_2O 1·74 %. In the fine-banded adinoles associated with and below these, there was found the complete and undistorted cast of a trilobite, identified by P. Lake as a *Cyphaspis* which is shown in fig. 12, pl. xi.

At the same locality, the lower part of the cliff shows rocks with interesting structures (fig. 11, pl. xi): they consist of flattened bodies lying in the bedding planes, with cores of ferriferous calcite surrounded by and replacing a shell of very fine-grained albite and perhaps quartz. These bodies are sharply marked off from the surrounding rock which

slice, appears as a mass of very fine sericite with much carbonate now presented by limonite. Partial analysis of this groundmass shows Na_2O 1·37, K_2O 2·95 %, indicating that the rock is only partially bitized. The nodules may be interpreted as the result of localized actions of solutions which found an easier path along the bedding anes: first, soda-rich solutions giving the adinole shell, and then solutions rich in the carbonates of lime and iron. Very similar nodules occur the contact of the Stepper Point dike and the purple Upper Devonian ates at Stepper Point quarry [17, plate 2]. This explanation does not old for the compound globules so typically developed and no satisfactory explanation has been found for this rhythmic phenomenon. It may present some process at a late stage in metamorphism, either the troduction of carbonates or the recrystallization of the original carbonates in the rock.

4. *Polygonal and spherulitic adinoles.*

The typical spherulitic adinole found by Fox [6] occurs only in two aces: in the small projection of Dinas Head into Stinking Cove and at e top of the cliff directly above this. The development of the rocks is arest at the latter locality. The outcrop of adinoles in which the herulitic type occurs has been torn away from its igneous contact and ided into the slates. On its western side it is separated by a quartz-led fault from normal adinoles which can be seen to pass into slates, though the tracing of any one particular band is a matter of great fficulty. It is probable that the spherulitic adinoles and associated ocks lay between these normal adinoles and the igneous contact, for on e whole they are more altered. The actual outcrop of the typical lygonal and spherulitic adinoles occupies a band not more than two et thick in between adinoles showing the simplest of structures. The tructures to be described must therefore depend to some extent on the iginal composition of the band.

(*a*) *The polygonal adinole* is a fine-grained white-weathering rock composed of a series of irregular polygons 5–10 mm. in diameter and showing o elongation, and through which in sections across the bedding, a fine anding can be seen (fig. 9 A). It is composed of an aggregate of very ne albite and quartz with a little chlorite and leucoxene, and with anding marked by rather thin and diffuse carbonaceous films. Analysis this rock shows Na_2O 8·94, K_2O 0·14 %. The polygons are defined by racks in which occur carbonaceous and ore minerals. Ankerite may ccur in them as small rhombs and stringers replacing the adinoles at the

margins of the polygons and therefore of a later date. Very thin quartz veins cut all these features.

These polygonal adinoles have been observed at the margins of joints in a fine structureless adinole, where they bear the same relation to this adinole as the spherulitic variety bears to them. This would seem to indicate that the structure post-dates the metasomatism or is a late feature of the process.

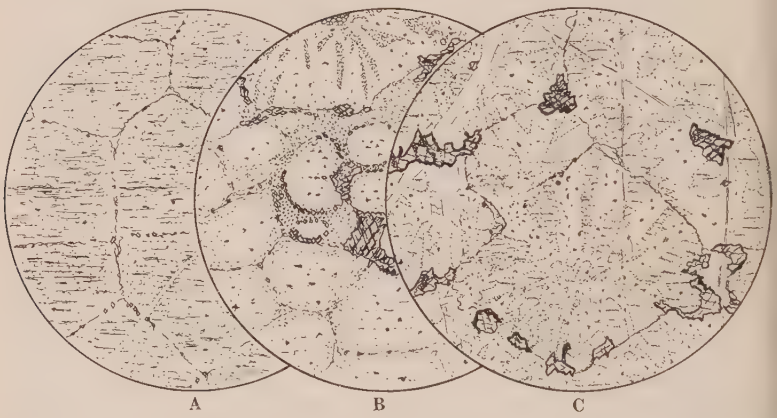


Fig. 9 A. Polygonal adinole. Very fine-grained quartz and albite with banding marked by carbonaceous films and polygons defined by limonite and ores; cut by a thin quartz vein. ×4.

Fig. 9 B. Adinole showing transition from polygonal to spherulitic structures. ×4.

Fig. 9 C. Spherulitic adinole. Radiating blades of albite are set in a matrix of fine-grained albite and quartz; the matrix partly replaced by ankerite between the spherulites. ×4.

(*b*) *The spherulitic adinole* is developed in most cases within 15 cm. of joints in the polygonal adinole and away from these is very local, disappearing both along and across the sedimentary banding. It weathers with a rough surface, as the individual crystals and spherulites stand out; and the finer details of the sedimentary banding are not generally visible on the weathered surface.

Examination of slices shows that the following changes take place in passing from polygonal to spherulitic adinole:

i. There is a marginal increase in the grain-size of the albite of the polygons, the grains still retaining their sutured interlocking margins.

ii. A disappearance of the fine banding marked by the carbonaceous films in the groundmass.

iii. Associated with the ankerite between the polygons, tabular bite and a little quartz are developed (fig. 9 B). Both these may place to some extent the fine adinole between the spherulitic blades albite.

iv. Albite develops as coarse blades up to 0·5 mm. across and arranged a spherulitic manner [cf. 7, fig. 57 C]. There are three distinct types this development. (*a*) Blades radiate from the centre of a polygonal ea and increase in width towards the margin. Albite twin-lamellae cur parallel to the length. Where these blades are not in contact ith each other they have crenulate margins, the end in particular being ry irregular and also fan-like, due to many new growth-centres ing set up. The blades are always cloudy and often have trains carbonaceous inclusions through them parallel to the original sedi-ntary banding, and independent of the orientation of the crystal g. 9 C). The blades of albite may be strongly curved and the twin-plane also curved, and the extinction varies parallel to it, but is constant th reference to the portion of the twin-plane to which it is adjacent. e number of spherulites increases towards the joints. (*b*) Blades may liate from within the polygon but not from its centre, which is still e-grained adinole. The blades in this case show features similar to se just described. It should be noted that in both these cases the des may not reach the margin of the polygon, and if they do so, they not grow into the adjacent polygon. The albite of the margin may be tured and interlocking, or tabular; that of the interior may be coarse, in iii, and show no banding. Opaque masses of zoisite are occasionally veloped at the centres of some of the polygons. (*c*) Blades of albite liate from thin quartz veins in the joints, and together with late kerite may show a fan-like form due to the periodic appearance of w centres of growth. These are usually set in irregular coarse albite.

v. Leucoxene is found most abundantly in the fine adinole between e spherulitic blades, or, if this is absent, at the mutual interference of o blades, where it occurs as coarse granules. It occurs only sporadi-lly as fine grains in the blades.

vi. Thin quartz veins, with albite crystals growing from the adinole ich forms the margin of the vein, are common.

Partial analysis of a spherulitic adinole immediately adjacent to the lygonal adinole, whose Na_2O and K_2O content has already been given, ows Na_2O 8·33, K_2O 0·17 %. A similar adinole showing both polygonal d spherulitic structures has been analysed by Fox [5, p. 723] and the mposition is given under D in table II.

(*c*) *The origin of the polygonal and spherulitic structures.*—The polygons are confined almost entirely to one band in the adinole, and must either represent some original structure in the sediment, or be due to a slight contraction during the process of metasomatism. Any other explanation meets with difficulty, because the very fine banding which runs undisturbed across from one polygon to another can be only of sedimentary origin.

The spherulites occur everywhere associated with the polygonal adinoles. They are more concentrated near small joints, and this fact, together with their common development within polygons, shows that they have grown after these were formed, possibly at a later stage in the metasomatism by the influence of water vapours acting along the joints. The change is one of gradual recrystallization, for the percentages of potash and soda are nearly identical in the polygons and spherulites, and the fine carbonaceous banding of the original polygonal adinole is preserved in the diversely orientated crystals of the spherulites. Those blades which start growth from thin quartz veins have done so because the water made conditions most suitable for recrystallization. These spread through the rock, the fan-like form being due to several points on the outside of the limit of crystallization starting as independent growth-centres.

(*d*) *Other types of spherulitic adinole.*—Just west of the typical spherulitic adinoles in the cliff on the north side of Dinas Head occur some highly folded adinoles composed essentially of albite and quartz. In these occur some bands which weather with rounded blebs about $\frac{1}{4}$ inch in diameter. In slice, the groundmass is almost entirely albite as sutured, interlocking grains of very variable size with many larger cloudy crystals with crenulate margins, the whole appearing as if it were being recrystallized into these coarser grains. Set in this groundmass are spherulites showing both a radial and a concentric structure. Sometimes these spherulites are joined together in a line parallel to the banding of the rock and appear like a vein with regular constrictions. Equiangular crystals make the core and are sometimes followed by a thin zone of fine-grained adinole. This is succeeded by a zone of radially arranged albites, then by a fine-grained zone which merges into the groundmass. No explanation of this rhythmic phenomenon is known.

In the most easterly knoll, sticking up through the grass on the south side of Dinas Head, adinoles of normal type occur, and interbanded with them are some which show spherulitic structures. The coarsest type is evidently an adinole breccia of rounded and angular masses of normal

inole which sometimes shows a zonary structure of a coarser core and ier shell, surrounded by radially arranged blades of albite up to 1 cm. length. These are turbid as a result of weathering. They could repre- nt some easily albitized rock of which no trace remains, and which may ve lost volume on metasomatism, and in the cavities resulting albite veloped. This, however, is unlikely, as the blades of albite are set in ine-grained groundmass like that of the normal spherulites. It is also ssible that they represent a rock with structures which have since en replaced, and a more easily albitized groundmass, but no parent ck suitable has been found at Dinas Head.

5. *Sheared adinoles.*

At several places to the north and south of Dinas Head the adinoles ve been sheared, either in faults or in the drawn-out limbs of folds. tash and soda were determined in one example of a rock from the ib of a folded and sheared adinole. The rock was composed entirely of ite mica and some small needles of rutile, and it was thought that the mer might be paragonite produced by the shearing of the adinole. alysis, however, showed Na_2O 0·38, K_2O 5·29 %. This indicates that mica is a normal muscovite.

VIII. The Chemical Constitution and Origin of Adinoles.

The chemical composition of adinoles given in table II is, as is to be pected from the mineralogical composition, essentially that of albite l quartz. As a result they show a very close chemical similarity to rtz-keratophyres, an average analysis of which is quoted in column F. eratophyric tuffs with more alumina-rich material would show a close emblance to the chemical composition of spilosites.

These resemblances have been brought out in a general way by plot- g the fields of the available analyses of adinoles, spilosites and spotted tes, pelitic sediments, and keratophyres on a ternary diagram (fig. 10) ose co-ordinates are: $Na_2O+Al_2O_3$, 1:1, i.e. equivalent to albite; O+residual Al_2O_3, i.e. equivalent to orthoclase and sericite; Fe_2O_3+ O+MgO+CaO, i.e. ferromagnesian minerals.

It should be noted that there is a transition between the fields of noles, spilosites, and slates, as would be expected if the origin of the former be due to the metasomatism of unaltered pelitic sediments. e similarity of mineralogical and chemical composition of adinoles and eratophyric lavas and tuffs suggests the possibility that some rocks, ich have been described as adinoles and hence as of metasomatic

origin, are, in reality, keratophyric lavas or tuffs which have been altered by pure thermal metamorphism at the contact of basic dikes and sills.

TABLE II. Chemical analyses of adinoles and spilosites.

	6.	B.	7.	8.	C.	D.	E.	F.
SiO_2 ...	52·70	54·02	70·86	69·03	66·6	64·6	72·63	75·45
TiO_2 ...	0·64	—	0·50	0·47	0·8	1·2	—	0·17
Al_2O_3 ...	25·28	21·22	15·17	17·42	19·6	20·4	15·81	13·11
Fe_2O_3 ...	0·68	2·51	1·52	0·17	0·9	0·7	—	1·14
FeO ...	1·59	6·48	1·06	0·71	0·2	—	0·74	0·66
MnO ...	trace	1·74	0·00	0·00	—	—	—	0·29
MgO ...	2·16	3·01	1·08	0·47	0·3	0·1	1·21	0·34
CaO ...	2·48	1·64	0·64	1·00	0·4	1·3	1·02	0·83
Na_2O ...	3·35	3·36	7·58	8·89	9·8	10·1	8·33	5·88
K_2O ...	5·16	3·71	0·25	0·31	0·7		0·75	1·26
H_2O+...	3·62	1·97	1·05	0·64	0·8	1·6	0·61	0·69
H_2O-...	0·70	—	0·38	0·24	—	—	—	—
B_2O_3 ...	0·15	—	0·35	0·00	—	—	—	—
P_2O_5 ...	0·12	—	trace	0·12	—	—	—	0·18
CO_2 ...	1·48	—	0·00	0·66	—	—	—	—
C ...	0·00	—	0·00	0·00	—	—	—	—
Total ...	100·11	99·66	100·44	100·13	100·1	100·0	101·10	100·00
Sp. gr....	2·59	2·78	2·63	2·62	—	—	2·68	—

6. Spilosite showing albite-rich spots with tourmaline needles in sericitic groundmass, Dinas Head (figs. 3 and 6A). Analyst, W. H. Herdsman.

B. Spilosite, Heinrichsburg, Mägdesprung, Harz [10].

7. Adinole, interbanded with 6, and showing fine-grained albite and quartz with coarser, and needles of tourmaline, Dinas Head (fig. 6 B). Analyst, W. H. Herdsman.

8. Adinole, very fine-grained structureless albite-quartz-rock, Dinas Head. Analyst, W. H. Herdsman.

C. Adinole, very fine-grained structureless albite-quartz-rock, Dinas Head [6].

D. Adinole, showing polygonal and spherulitic structures, Dinas Head [6].

E. Adinole, Heinrichsburg, Mägdesprung, Harz [10].

F. Average quartz-keratophyre. (R. A. Daly, Igneous rocks, 1914, p. 20.)

The rocks from Dinas Head described as adinoles are very much thicker than other recorded adinoles, especially those associated with dikes and sills of the same province in Devon and Cornwall. Also, these adinoles from Dinas Head occur at about the same horizon as the calcareous slates and keratophyric ash of Greeb Point in Veryan Bay [8, table I], and must resemble the latter very closely in chemical composition. It is evident, therefore, that keratophyric material was available in Devonian time in south Cornwall, and the existence of keratophyric tuffs in north Cornwall would not have been unexpected.

With these points in mind, a careful examination was made of all the evidence at Dinas Head. The following features indicate that the

dinoles were derived from a sediment, but do not indicate whether this diment was tuffaceous or not:

i. A very prominent banding shows well in the differential weather-g of the adinoles. This banding is sometimes so fine as to be most rominent when seen under the microscope. It is not prominent in the roup 3 adinoles with the globular ankerite structures.

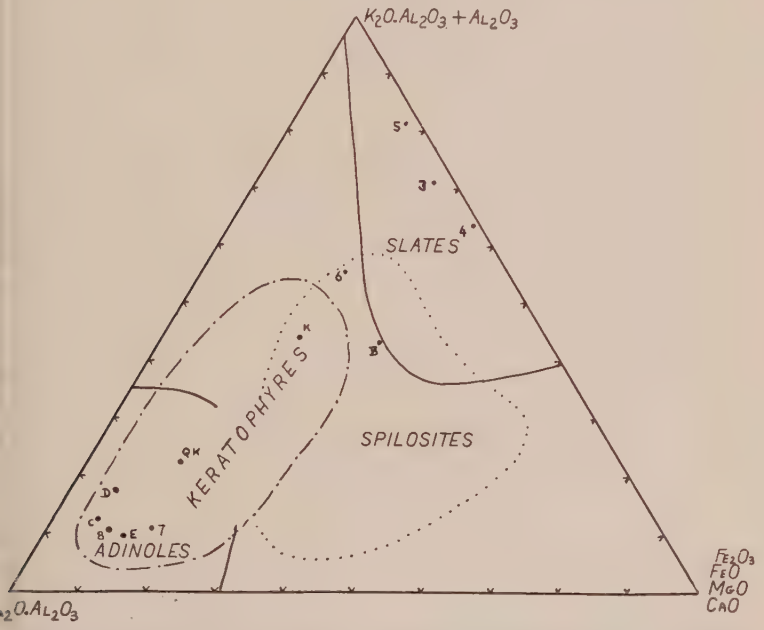


Fig. 10. Diagram to show the fields of slates, spilosites, adinoles, and keratophyres, based on 170 analyses. The numbers correspond to analysed rocks from Dinas Head. QK = average quartz-keratophyre. K = average keratophyre.

ii. Fossils, completely undistorted, are present in some of the adinoles g. 12, pl. xi).

iii. The adinoles form a shell over the dolerite intrusion and lie tween it and the unaltered slates and limestones. It should, however, noted that this would also describe a concordant intrusion into a lava into a tuff horizon.

The following additional features point to a metasomatic as well as a dimentary origin:

iv. There is a general increase in albitization towards the contact with lerite, visible where the rocks are not folded or torn away from it.

v. Pseudomorphs, presumably after andalusite, occur in one of the common types of adinole.

vi. Spilosite with small albite and dravite spots in a sericitic base like that of a normal slate is intimately interbanded with adinole in which the spots are preserved as coarser patches in a fine-grained adinole representing the altered groundmass of the spilosite.

vii. Pyroclastic characters, some trace of which might be expected to be preserved, are completely absent in all the types of adinoles. Except for the thin band of schalstein in the unaltered sediments, tuffs are absent.

The only adinoles which do not show an abundance of sedimentary features are the types with the globular masses of ankerite from the south side of Dinas Head, but even these show a rude banding and sometimes the relicts of initially albitized spots in the groundmass of fine adinole. Their lack of positive volcanic or pyroclastic features makes it more probable that they are of sedimentary and metasomatic origin like the rest of the adinoles.

The metasomatic origin of these adinoles being thus extremely probable, an attempt can now be made to investigate the process of adinolization more closely.

The earliest workers, Kayser [10], Lossen [12], Fox [5, 6], and Clements [2], all based their suggestions on evidence from the minerals developed in adinoles and albite-dolerites and on analyses of these and slates without any definite calculation as to the amount of material transferred. The first attempt to calculate the material added to a slate to form adinole was made by Dewey [4, p. 75], who used a straight line variation diagram and arrived at the conclusion that it was necessary to add four parts of albite and a small quantity of magnetite to one part of slate to give the adinole. Holmes [9], using Dewey's diagram slightly modified, calculated that to one part of shale, six times its weight in albite has been added. Blyth [1] concluded that albitic solutions permeated the shales, but he made no suggestions as to the amount of material involved. Milch [14] added material, of a composition which it seemed reasonable to regard as corresponding to the late liquids of the albite-diabases, to a given amount of sediment until the average composition was that of the analysed material.

All the above methods of calculation imply a great increase in volume (or a great increase in density) accompanying metasomatism, and for this there is no evidence anywhere whence adinoles have been described. One finds that everywhere there is essentially a volume-for-volume

placement of the slate. The evidence upon which this is based is as lows:

i. In some of the adinoles the very finest of banding, presumably limentary, is visible and shows no sign of the distortion which might caused if the chemical change was accompanied by an increase in lume. The irregular banding described in the chlorite-rich adinoles ıy be a result of such an increase, but even so, this type is relatively tricted in its development.

i. The larger scale bedding of the adinoles themselves, or of the inoles and spilosites, shows all the features of a normal sediment with rallel-sided beds.

ii. There is a complete absence of cavernous structures in all adinoles, ept possibly in the third of the spherulitic types.

v. The fossils found in adinole both at Dinas Head and at Port Quin , p. 26] are perfect casts and show that the replacement of slate by nole is a gentle replacement of the original structures by the new erals.

The early-formed andalusites, now pseudomorphed by quartz and rite, are undisturbed by the process which albitized the micaceous undmass in which they are set.

ii. There has been no great increase in the density of the rocks such ight be accounted for by the addition of much material.

hat this constancy of volume must be the control we use in calcu- ng the changes that take place in metasomatism was pointed out by some [15]. Calculations are made on 100 c.c. of material. The ghts in grams of the various oxide components per 100 c.c. are ained from the weight present in 100 grams of rock, by multiplying percentage value by the specific gravity of the rock. In table III a calculation is worked out on the assumption that the grey-black e analysed is the parent sediment. Columns A_1, B_1, C_1, D_1, and E_1 weights in grams of each oxide per 100 c.c. of rock. Columns B_2, D_2, E_2 show the gains and losses of each oxide in each of the altered es as compared with the grey-black slate. The values are obtained direct subtraction, the plus values indicating material added and the us values material lost during the adinolization. The total amounts aterial lost and gained are obtained by adding the plus and minus es respectively, and the net gain or loss of material in adinolization ach rock is given by the difference in these totals. This indicates that it 47 grams of material were added and 76 grams lost per 100 c.c. ate adinolized, or 17 grams replaced 23 grams in 100 grams of rock.

This is a much more reasonable result than the addition of three to six times the weight of slate in albite and quartz.

TABLE III. Gains and losses during adinolization, assuming the black slate (analysis 3, table I) to be the parent sediment.

Weight of each constituent as grams per 100 c.c. of rock.						Gains and losses as grams per 100 c.c. of rock, compared with 100 c.c. of the black slate.				Gains and losses as percen of the original rock mass as grams per 100 gram rock.			
	A_1	B_1	C_1	D_1	E_1	B_2	C_2	D_2	E_2	B_3	C_3	D_3	
Analysis No.	3.	5.	6.	7.	8.	5.	6.	7.	8.	5.	6.	7.	
SiO_2	160·1	176.2	136·5	187·1	180·8	+16·1	−23·6	+27·0	+20·7	+5·7	− 8·4	+ 9·6	+
TiO_2	1·7	1·6	1·7	1·4	1·2	− 0·1	—	− 0·3	− 0·5	—	—	− 0·1	−
Al_2O_3	62·8	56·7	65·5	40·1	42·3	− 6·1	+ 2·7	−22·7	−20·5	−2·2	+ 0·9	− 8·1	−
Fe_2O_3	1·8	2·4	1·8	4·0	0·5	+ 0·6	—	+ 2·2	− 1·3	+0·3	—	+ 0·8	−
FeO	14·5	5·1	4·1	2·8	1·9	− 9·4	−10·4	−11·7	−12·6	−3·3	− 4·1	− 4·2	−
MgO	8·0	4·2	5·6	2·9	1·2	− 3·8	− 2·4	− 5·1	− 6·8	−1·4	− 0·9	− 1·8	−
CaO	1·7	—	6·4	1·7	2·6	− 1·7	+ 4·7	—	+ 0·9	−0·6	+ 1·7	—	+
Na_2O	1·4	0·9	8·7	20·0	23·3	− 0·5	+ 7·3	+18·6	+21·9	−0·2	+ 2·6	+ 6·6	+
K_2O	12·8	13·1	13·4	0·7	0·8	+ 0·3	+ 0·6	−12·1	−12·0	+0·1	+ 0·2	− 4·3	−
H_2O+	12·1	9·4	9·2	2·8	1·7	− 2·7	− 2·9	− 9·3	−10·4	−1·0	− 1·0	− 3·3	−
H_2O-	1·7	1·8	1·8	1·0	0·6	+ 0·1	+ 0·1	+ 0·7	− 1·1	—	—	+ 0·3	−
B_2O_3	—	—	0·4	0·9	—	—	+ 0·4	+ 0·9	—	—	+ 0·2	+ 0·4	
P_2O_5	0·3	0·3	0·3	—	0·3	—	—	− 0·3	—	—	—	− 0·1	
CO_2	—	—	3·8	—	1·7	—	+ 3·8	—	+ 1·7	—	+ 1·4	—	+
C	2·5	0·9	—	—	—	− 1.6	− 2·5	− 2·5	− 2·5	−0·5	− 0·9	− 0·9	
Total added per 100 c.c., in grams . .						+17·1	+19·6	+49·4	+45·2	+6·1	+ 6·8	+17·7	+
Total displaced, do. . .						−25·9	−41·8	−64·0	−67·7	−9·2	−15·3	−22·8	−
Net gain or loss, do. . .						− 8·8	−22·2	−14·6	−22·5	−3·1	− 8·5	− 5·1	−

	Composition of added material as weight %.				Na_2SiO_3
SiO_2	94·7	—	55·3	46·0	45·4
Al_2O_3	—	13·4	—	—	—
Fe_2O_3	3·6	—	4·4	—	—
CaO	—	24·3	—	2·0	—
Na_2O	—	38·0	38·1	48·5	54·6
K_2O	1·8	3·0	—	—	—
B_2O_3	—	1·5	1·2	—	—
CO_2	—	19·6	—	3·7	—

From the plus values the composition of the material added to th sediment has been calculated and is essentially Na_2O and SiO_2 with little B_2O_3 and possibly a little Fe_2O_3. It is interesting to recall at thi point that Clements [2] suggested that adinolization consisted of th addition of soda and silica to slates.

These ingredients need not correspond to the actual composition of th fluids permeating the rocks, but are the materials that have been 'fixed in the slate to give adinole. This 'fixation' may be the result both of simple chemical reaction capable of representation by an equation an of a replacement in which stoichometric relations do not hold, and becaus of this, one cannot give a balanced equation to express adinolization.

The values calculated in table III give the minimum amount of terial gained and lost in metasomatism, for only that amount of terial necessary to bring the composition of the slate to that of the tasomatized product is removed and added in the calculation. There nothing to indicate to what extent there has taken place a complete placement, such as, to take an extreme case, Sericite (solid)+Albite solution) —> Albite (solid)+Sericite (in solution).

Very similar results are obtained from a volume-for-volume calcula- n with the green spotted slate (analysis 4) as parent. It should, how- er, be pointed out that one does not know for certain whether the tes analysed were the actual parents of these particular adinoles, for, hough they occur near them, one cannot trace exactly the same band sediment into adinole.

The tourmaline (dravite) was possibly formed by reaction of the roduced boron with the chlorite of the original sediments; that it was roduced along with the soda and silica is shown by its presence in the ly metasomatic spots of the spilosites and by its association with ite of two generations in the spilositic adinole interbanded with the losites. If all the sediments were affected by similar solutions carrying $_2O$, SiO_2, and B_2O_3, the amount of tourmaline developed must be ntrolled by the initial composition of the sediments. Tourmaline is pical of the normal adinoles and occurs occasionally in the spherulitic inoles, but varies in amount. In some rocks it may be absent, in ers it is an accessory mineral, and in others is the predominant con- tuent. The presence of tourmaline so obviously formed along with the site and associated with basic igneous rocks is of much interest, and e description and discussion of the origin of these types is reserved for eparate communication. It may, however, be recorded here that no rmaline or boron-bearing mineral has, as yet, been found in the site-dolerite, except an axinite-epidote gash vein in a newly opened arry.

There is some evidence to show that prior to the metasomatism there ok place a thermal effect due to the heat of the dolerite. Thus between e adinoles and spilosites showing metasomatic effects and the un- ered sediments there are, in several places, slates which show a aracteristically thermal spotting, such as is found at the contact of ny dikes and sills in the Devonian slates of north Cornwall. These ots show no evidence of added material and are due to the selective ncentration of chlorite, sericite, ores, and graphite, and may be attri- ted to the active nature of the water contained in the rock, as a result

of a slight rise in temperature in the vicinity of the igneous intrusion, bu outside its sphere of metasomatism.

Other spotted slates show a variety of chevron-like forms such as have elsewhere been ascribed to incipient andalusite or cordierite [17, pp. 49-50; 18, p. 65]. This may quite well be the case, as the examples analysed agree closely with class I hornfelses near the andalusite-cordierite join. In the chlorite-rich adinoles there are coarser patches of albite with these chevron features marked in chlorite. These may represent replacements of what is described as incipient andalusite or cordierite in the spotted slates.

Within twenty to thirty feet of igneous contacts are found bands containing pseudomorphs of andalusite replaced by quartz and chlorite (group 2 *a* and 2 *b*), set in a fine-grained matrix of albite and quartz. This andalusite must have formed in the argillaceous sediment prior to the metasomatic development of albite. The pseudomorphs are found close to the contact, as only here was the heat of the dolerite sufficient to complete the mineralogical change. The presence of andalusite so well developed at a dolerite contact is very exceptional, but as no other intrusion is to be seen, all the evidence points to the dolerite being the source of both the supply of heat and of the metasomatizing fluids.

In the metasomatic stage there are two facts which indicate that silica-rich fluids may have preceded the soda-silica-rich fluids responsible for the albitization. Firstly, some of the spilosites on the outside of the metasomatic aureole show small quartz-rich spots. It is not proven, however, that these represent material added from an external source. If this rock is to be regarded as a parent of the adinoles, a volume-for-volume calculation shows that it would be necessary to add soda and accessory silica to it to give adinole. Secondly, the andalusites formed in the early thermal stage of metamorphism are commonly replaced by coarse quartz and chlorite, and set in a matrix of very fine-grained albite and quartz.

Carbonates everywhere crystallize after the albitization and are found as isolated crystals, veins, nodules, and bands, all showing some replacement features against the adinole. Both ankerite and calcite occur in the adinoles, and the igneous rock is so highly carbonated that there is no doubt that all of it could have been derived from the intrusion. On the other hand, calcite is plentiful in some of the unaltered slates among which limestone bands also occur, so that the calcite at least might be derived from these sediments, and shows late crystallization and replacement features because of its ability to exist in solution in the rock

lower temperatures when albitization has ceased. In all probability, wever, both these sources were important.

In table III it will be noted that the spilosite 6 gives very different ults from the adinoles 7 and 8. This must be due to a difference in nposition of the original sediment, for 6 and 7 are interbanded (fig. 3). om the analysis it would appear that this spilosite was much richer in mina than any of the analysed slates, but there is no evidence to w that this factor alone is the reason for the resistance of this rock albitization. Had this spilosite been completely adinolized—and no ibt beds of an initially similar composition are represented among the noles—it would have been very similar chemically and mineralogi-ly to the analysed adinoles 6 and 7.

In this connexion it is worth noting that red and purple slates may adinolized close to dolerite contacts, contrary to Dewey's statement p. 72] that they are converted only into spotted slates. Thus at the tact of the Stepper Point dike and the red and green slates of Butter ie and Pepper Hole [17, p. 22] there is a six-inch band of adinole mediately adjacent to the dike. Between this and the unaltered slates re is a zone, 50–80 feet wide, of spotted slates which sometimes show pient andalusite. Below the quarry at Stepper Point, the spotted ple slates have nodules of adinole close to the contact [17, plate 2].

It seems, therefore, that in the initial stages of adinolization the city of reaction is controlled by the composition of the sediments, , as Dewey suggests, it is probably the richness in Fe_2O_3 of the red es which inhibits their reactions with the metasomatic fluids, to-her with the fact that in black slates the iron is mostly in chlorite and refore in the ferrous condition and so more susceptible to reaction. this were the only cause, the pale-green slates which are richer still FeO ought to develop adinoles easily, but this is not so, as adinoles he pale-green slates are very thin. It is suggested, therefore, that the in-size of the original sediment exerts an important influence on the e with which the rock is albitized: for the red and pale-green slates the centre of the St. Mabyn syncline are much coarser in grain-size n are the black slates occurring on the flanks of the syncline.

The composition of the minerals formed, and hence of the end-product nole, are controlled by the metasomatic fluids emanating from the eous rock. The end-product will have exactly the same minerals as se formed in the earliest stages of metasomatism provided that the nposition of the fluids has not changed. Thus, in the first stages of tasomatism, albite, quartz, and chlorite, with or without dravite, are

formed. In the adinoles which represent complete metasomatism, the rock is built up entirely of the same minerals with or without carbonates. These carbonates, in part at any rate, correspond to an addition of carbonate to the original fluids containing soda, silica, and boric oxide. It is also evident that very different replacements must take place in the adinolization of different rocks, for adinoles which are mineralogically and chemically identical are formed from a variety of argillaceous types.

All the metasomatizing material has been derived from the albite-dolerite, and it can be shown that if it were added back to the rock, it would still have the composition of a fairly typical member of the suite of Devonian hypabyssal intrusions allied to the spilites. Thus, assuming that there is four times as much dolerite as adinole—and there is certainly more than this—from table III the following figures are obtained: 100 c.c. slate become 100 c.c. adinole by the addition of 20 grams (approx.) of Na_2O and 24 grams SiO_2. This adinole we have assumed is derived from 400 c.c. of dolerite, so to each 100 c.c. of dolerite, 5 grams of Na_2O and 6 grams of SiO_2 must be added. The dolerite has 46·9 % SiO_2, equivalent to 135·1 grams of SiO_2 per 100 c.c., and 3·8 % Na_2O, equivalent to 10·9 grams of Na_2O per 100 c.c., since the specific gravity is 2·88. With the added material this becomes 141 grams SiO_2 and 16 grams Na_2O per 100 c.c., which, as weight per cent., is SiO_2 48·9 %, Na_2O 5·5 %. The reason for this great bulk of adinole at Dinas Head compared with other localities must lie in the greater bulk of igneous material which supplied the metasomatic fluids. These fluids were probably identical with the late autolytic fluids which albitized, carbonated, and chloritized the dolerite. On account of the thickness it is possible that the intrusion is a small plug-like mass with sill-like offshoots on its upper surface, as was suggested when the igneous rocks were described. The offshoots enabled a more intimate penetration of the sedimentary series to be brought about.

This study was carried out during the tenure of a grant from the Department of Scientific and Industrial Research, and the cost of the analyses was defrayed partly by a grant from the Royal Society. Both these grants are gratefully acknowledged. The writer wishes to express his thanks also to Professor C. E. Tilley for the helpful criticism and advice proffered throughout the course of the work.

Fig. 11

Fig. 12

Fig. 13

Fig. 14

S. O. Agrell: Adinoles from Cornwall

IX. Publications to which Reference is Made.

. Blyth (F. G. H.). The basic intrusive rocks associated with the Cambrian inlier near Malvern. Quart. Journ. Geol. Soc. London, 1935, vol. 91, pp. 463–478.
. Clements (J. M.). A contribution to the study of contact metamorphism. Amer. Journ. Sci., 1899, ser. 4, vol. 7, pp. 81–91.
. Daly (R.A.). Igneous rocks and the depths of the earth. New York and London, 1933.
. Dewey (H.). On spilosites and adinoles from north Cornwall. Trans. Roy. Geol. Soc. Cornwall, 1915, vol. 15, pp. 71–84.
. Fox (H.). Notes on the cherts and associated rocks of Roundhole Point (Permizen Point), Cataclews Point, and Dinas Head, west of Padstow. Trans. Roy. Geol. Soc. Cornwall, 1895, vol. 11, pp. 687–724.
. —— On a soda felspar rock at Dinas Head, north coast of Cornwall. Geol. Mag. London, 1895, dec. 4, vol. 2, pp. 13–20.
. Harker (A.). Metamorphism. London, 1932.
. Hendriks (E. M. L.). Rock succession and structure in south Cornwall, a revision. Quart. Journ. Geol. Soc. London, 1937, vol. 93, pp. 322–367.
. Holmes (A.). Petrographic methods and calculations. Second edition, London, 1930, pp. 464–467.
. Kayser (E.). Ueber die Contactmetamorphose der körnigen Diabase im Harz. Zeits. Deutsch. Geol. Gesell., 1870, vol. 22, pp. 103–172.
. Kunitz (W.). Die Mischungsreihen in der Turmalingruppe und die genetischen Beziehungen zwischen Turmalinen und Glimmern. Chemie der Erde, 1930, vol. 4, pp. 208–251.
. Lossen (K. A.). Ueber den Spilosit und Desmosit Zincken's. Zeits. Deutsch. Geol. Gesell., 1872, vol. 24, pp. 701–786.
. McMahon (C. A.) and Hutchings (W. M.). Note on pseudo-spherulites. Geol. Mag. London, 1895, dec. 4, vol. 2, pp. 257–259.
. Milch (L.). Über Adinolen und Adinolschiefer des Harzes. Zeits. Deutsch. Geol. Gesell., 1917, vol. 69, pp. 349–486.
. Ransome (F. L.). Geology and ore-deposits of the Breckenridge district, Colorado. Prof. Paper U.S. Geol. Surv., 1911, no. 75, pp. 96–99.
. Winchell (A. N.). Elements of optical mineralogy, Part II. Third edition, New York and London, 1933.
Mem. Geol. Surv. Great Britain, Explanation to Sheets 335 and 336, Padstow and Camelford. By C. Reid, G. Barrow, and H. Dewey, 1910.
Mem. Geol. Surv. Great Britain, Explanation to Sheet 339, Newton Abbot. By W. A. E. Ussher, 1913.

Explanation of Plate XI.

Adinoles of Dinas Head, Cornwall.

Fig. 11. Disk-like nodules lying in the bedding planes of a partially adinolized te; showing the core of calcite surrounded by a shell of adinole. From the south e of Dinas Head.

Fig. 12. Trilobite (*Cyphaspis*) in adinolized slate from the south side of Dinas ad. ×2.

Fig. 13. Pseudomorphs of andalusite replaced by quartz and a little calcite, set adinolized slate. From the south side of Dinas Head. ×½.

Fig. 14. Adinole with concentric structures of ankerite. From the south side Dinas Head. ×¾.

An X-ray examination of some potash-soda-felspars.

By S. H. Chao, D. L. Smare, and W. H. Taylor,

Physics Department, College of Technology, Manchester.

[Read January 26, 1939; communicated by Prof. W. L. Bragg, F.R.S.]

I. Introduction.

THE systematic classification of the potash-soda-felspars is of the greatest interest and importance to the mineralogist, but problems demanding physical investigation are raised in work carried out recently by Dr. Edmondson Spencer,[1] who has described the results of exhaustive chemical, optical, and thermal investigations of a representative collection of these minerals. Dr. Spencer has very kindly allowed us to examine by X-ray methods a large number of his specimens, so that for the first time it has been possible to make a fairly complete survey of potash-soda-felspars of known chemical composition and with accurately measured optical properties.

This paper presents the results of our general survey of potash-soda-felspars with compositions ranging from nearly pure potash-felspar to approximately 50 % soda-felspar. The natural minerals, and the same minerals after specified heat-treatment, have been examined. We do not discuss in detail the interpretation of our results in terms of the atomic structure of felspars;[2] the subject is extremely complicated, and it is necessary to await the results of other investigations now in progress in this laboratory before attempting a complete structural interpretation.

Spencer's measurements, and especially those concerned with the effects due to various heat-treatments, show conclusively that the classification of the natural minerals can only be achieved when the physico-chemical problem of their constitution has been solved, a mere descriptive classification being impossible by reason of the large number of variables involved. Those of his conclusions which are important for

[1] E. Spencer, Min. Mag., 1930, vol. 22, p. 291; 1937, vol. 24, p. 453; 1938, vol. 25, p. 87.

[2] W. H. Taylor, Zeits. Krist., 1933, vol. 85, p. 425 [M.A. 5–473]; W. H. Taylor, J. A. Darbyshire, and H. Strunz, ibid., 1934, vol. 87, p. 464 [M.A. 6–177].

e present work may be summarized very briefly as follows: (i) The turally occurring perthitic potash-soda-felspars may be divided into o main groups, the orthoclase-microperthites and the microcline-croperthites; within each group the optical properties and specific vity vary in a regular way with the chemical composition, but the riation laws are different for the two groups. (ii) On heating micro-thites for short periods at temperatures not exceeding 850° C. pprox.), the perthitic structure disappears, the schiller vanishes, the ecific gravity and refractive indices are reduced, but there is no change the optic axial angle. On cooling, the perthitic structure reappears d the other changes are reversed. The extent and rapidity of the anges depend upon the composition and the microperthite type thoclase or microcline), but they are essentially reversible and repre-t solution (on heating) or separation (on cooling) of the soda-rich croperthitic lamellae. (iii) On heating for long periods at temperatures proaching the melting-point an irreversible change takes place, and resulting homogeneous or 'sanidinized' felspars have the low optic al angle which is associated with natural sanidine. On cooling slowly ough the normal perthite exsolution range (800–400° C.), these nidinized' felspars show no trace of exsolution.

It has already been suggested (Taylor, Darbyshire, and Strunz, 1934) t the lamellae in perthitic structures represent segregations of cations a tetrahedron framework which is essentially continuous throughout crystal but is modified locally to accommodate the large potassium s and small sodium ions respectively. It seems clear that in the ocesses described in detail by Spencer and summarized above, we are ncerned with the problem of diffusion of ions in a crystalline structure i with the slight modifications of structure which are a consequence the diffusion.

The results of earlier X-ray examinations of perthitic felspars have en reviewed by Spencer (1937, p. 484) and need not be discussed here. and Inuzuka have recently shown[1] that X-ray powder photographs microperthites possess features which are not explicable on the umption that the perthitic structure is due to sub-microscopic nning of structurally identical individuals, but are explained if is supposed that two structures are present, one similar to pure ash-orthoclase, the other similar to albite. This conclusion is in eement with the results of earlier work, and is confirmed by our ults.

[1] T. Ito and H. Inuzuka, Zeits. Krist., 1936, vol. 95, p. 404 [M.A. 7–32].

II. Untreated Orthoclase-microperthites.

We have determined the axial lengths of orthoclase-microperthites with compositions which range from 96 % potash-felspar (specimen A) to 44 % potash-felspar (specimen R). The axes have been determined from measurements on X-ray photographs obtained by rotating small fragments of crystal about each of the axes *a*, *b*, and *c* in turn, using molybdenum K_α radiation of wave-length $\lambda = 0{\cdot}710$ Å. The axial lengths for both untreated and heat-treated materials are collected in table I and represented graphically in fig. 1. The accuracy of the measurements is discussed later (section IV). The specimens are lettered in accordance with the lists in Spencer's second paper (1937, p. 455 and pl. xviii). The conclusions which may be drawn from the experimental data are set forth in the following paragraphs.

(i) *The nature of the lamellar structure.*

Specimens A and C are free from schiller and show no trace of perthitic structure under optimum conditions of illumination (Spencer, 1930). In conformity with this optical behaviour, rotation photographs from these specimens are typical of a single crystal of monoclinic symmetry. By contrast, specimens M and R show a clear blue schiller and perthitic structure, and the rotation photographs contain, in addition to sets of reflections similar to those in photographs from specimens A and C, extra sets of reflections. The extra reflections must be due to the increased soda-felspar content of the crystal, since they become gradually more intense in passing along the series of specimens, from E (17 % soda-felspar), where they first appear, to F (21·5 %), I (30·5 %), J (36 %), M (42·5 %), R (56 %).

The arrangement of the extra reflections due to soda-felspar is relatively simple. On rotating an orthoclase crystal about the *a*-axis, the principal reflections (due to pure potash-felspar) are arranged in straight horizontal layer-lines (cylindrical film) with separations corresponding to $a_1 = 8{\cdot}6$ Å. approximately. The additional reflections (due to soda-felspar) are also arranged on layer-lines, parallel to the principal layer-lines, but corresponding to an axial length $a_2 = 8{\cdot}1$ Å. approximately. The soda-felspar is therefore present in the form of crystals with axis a_2 *parallel* to the principal axis a_1 of the potash-felspar component.

On rotating about the orthoclase *c*-axis, no additional layer-lines are seen, all reflections being included in a single set of layer-lines; this

ndicates that c_1 (for potash-felspar) and c_2 (for soda-felspar) are parallel nd equal in magnitude, the axial length being 7·2 Å. approximately.

On rotating about the orthoclase b-axis, the principal reflections are rranged in layer-lines corresponding to $b_1 = 13{\cdot}0$ Å. approximately, ut additional reflections are observed which increase in relative ntensity as the percentage of soda-felspar increases. In these photo-raphs the additional reflections are not arranged in straight layer-lines, ut are grouped as would be expected for a crystal with axis b_2 equal n magnitude to b_1 but inclined at a small angle ($\sim 3°$) to b_1.

The microperthitic crystal thus contains two components: one has xes $a_1 = 8{\cdot}6$ Å., $b_1 = 13{\cdot}0$ Å., $c_1 = 7{\cdot}2$ Å., and angle $\beta = 64°$, con-orms to monoclinic symmetry, and corresponds to pure (or nearly pure) otash-felspar; the other has axes $a_2 = 8{\cdot}1$ Å. (parallel to a_1), $b_2 = 13{\cdot}0$ Å. nclined at a small angle to b_1), $c_2 = 7{\cdot}2$ Å. (parallel to c_1), and angle $= 64°$, cannot conform dimensionally to monoclinic symmetry, and orresponds to pure (or nearly pure) soda-felspar.

(ii) *The structure of the soda-felspar lamellae.*

Since the unit-cell dimensions of the soda-felspar lamellae are identical, ithin the accuracy of our measurements, with the dimensions of the nit cell of albite (Taylor, Darbyshire, and Strunz, 1934), it would be atural to assume that the structure is also identical with that of albite. his is not the case.

In a rotation photograph of Amelia albite (Spencer's specimen S), ith rotation about the a-axis, the distribution and relative intensities f reflections for layer-lines corresponding to $h = 0$, 1, 2, are similar o those in the additional layer-lines in a photograph of an orthoclase-icroperthite; in layer-lines corresponding to $h = 4$, 5, there are quite bvious differences. The two structures must therefore be similar but ot identical. Further examination of the soda-felspar lamellae is to be ndertaken, with the aid of Weissenberg photographs. It already seems robable, however, that the major difference between the pure potash-lspar structure and that of the soda-felspar lamellae must be repre-ented by differences in the atomic co-ordinates parallel to the a-axis. or in a photograph of specimen M or specimen R, with rotation about he a-axis, the reflections on the additional layer-lines for $h = 0$, 1, or 2, orrespond in position and relative intensity with those on the principal ayer-lines, while reflections on the additional layer-lines for $h = 4$, 5, o not match those on the corresponding principal layer-lines.

The conclusion that the soda-felspar lamellae are not structurally

identical with albite is in agreement with Spencer's statement (1937, pp. 485, 486) that these microperthite lamellae appear to have optical properties different from those of ordinary albite, and that they never show multiple albite twinning.

It is highly probable that the various known forms of soda-felspar are similar but not identical in structure: with the help of further experimental data it may be possible to determine the precise structural features which differentiate ordinary (triclinic) albite, the (triclinic) soda-felspar lamellae of the orthoclase microperthites here described, the monoclinic soda-felspar known as barbierite, and the soda-felspar lamellae of the 'antiperthite' described by Barth.[1] In a private communication, Dr. Edmondson Spencer has suggested that the soda-felspar lamellae of our orthoclase-microperthites may in fact prove to be identical with the soda-felspar lamellae of Barth's 'antiperthite'.

(iii) *Optical and X-ray evidence of lamellar structure.*

It is of interest to examine whether the first appearance of optical inhomogeneity[2] in the series of orthoclase-microperthites coincides with the first appearance of additional reflections in the X-ray photographs.

Specimens A and C are optically homogeneous even under optimum conditions of illumination, show little or no sign of the changes on heat-treatment which characterize the lamellar microperthites, and give simple X-ray photographs corresponding to a single crystal having monoclinic symmetry.

Specimen D shows a faint blue-white schiller, and lack of homogeneity when examined microscopically, and in its behaviour under heat-treatment falls into the microperthitic group. No additional reflections can be detected on X-ray photographs with rotation about either *a*-axis or *b*-axis.

Specimen E is also lamellar, and shows a faint white schiller, but in *b*-axis photographs no trace of additional reflections can be detected, while in *a*-axis photographs the additional layer-lines (if present) are exceedingly faint—so faint that their real existence is doubtful.

Specimen F is lamellar with a blue schiller, and in *a*-axis photographs there are definite, though weak, traces of the additional layer-lines due to soda-felspar lamellae; in *b*-axis photographs, however, there is still no trace of additional reflections—i.e. all reflections, from both potash-felspar lamellae and soda-felspar lamellae, correspond to unit cells with identical and parallel *b*-axes.

[1] T. Barth, Zeits. Krist., 1929, vol. 69, p. 476 [M.A. 4–127].

[2] Optical data are taken from Spencer, 1937.

Specimen I is lamellar with clear blue schiller, and additional reflections are now clearly visible on both *a*-axis and *b*-axis photographs.

In the remaining specimens J, K, M, R the additional reflections become increasingly intense as the percentage of soda-felspar increases, but no new phenomenon is encountered.

It appears, therefore, that although specimens D, E, F are optically inhomogeneous, and specimens E (?) and F show additional layer-lines on *a*-axis photographs, the soda-felspar lamellae only assume their final stable form when the amount of soda-felspar is greater than 1·5 % by weight (specimen F); in specimen I (30·5 % soda-felspar) additional reflections appear in both *a*-axis and *b*-axis photographs. Additional evidence for this view is found in the comparison of values of the principal axis a_1 with the axis a of the heat-treated materials (table I and fig. 1): for specimens A, C, D, F the two axes are almost identical (no data for treated E); for specimens I, J, K, M, R the 'treated' *a*-axis is quite different from the 'untreated' a_1-axis. (See also section IV.)

It is probable that the soda-felspar lamellae exist, in D as well as in E and F, with a structure having a secondary axis $a_2 = 8{\cdot}1$ Å., but the axis b_2 identical in magnitude and direction with the principal axis b_1 of the potash-felspar. If this is the case, *a*-axis photographs of specimen D fail to reveal additional layer-lines merely because their intensity is too small.

It is obviously impossible to decide experimentally whether the same lamellation occurs in A and C as in D, but Spencer (1937) gives reasons for supposing that these specimens (containing 4 % and 9 % of soda-felspar respectively) hold the soda-felspar in solid solution, while D (6 % soda-felspar) is unable to do so.

(iv) *The sanidine structure.*

Specimen G (Eifel sanidine) is glass-clear and free from schiller although it contains more soda-felspar than specimens E and F) and has an abnormally low optic axial angle. Rotation photographs show no additional reflections due to soda-felspar. Its properties are thus similar to those of specimens which have been homogenized by prolonged heating at a temperature approaching the melting-point.

III. Homogenized Orthoclase-microperthites.

Table I and fig. 1 include data obtained from specimens which have been heated for 300 hours at 1075° C. and so have been homogenized or

'sanidinized'. All the specimens show a reduction in optic axial angle, the reduction being greater the smaller the percentage of soda-felspar (Spencer, 1937).

Rotation photographs about the *a*-axis now show a single set of layer-lines, corresponding to an axial length which varies from 8·6 Å. for specimen A (4 % soda-felspar) to 8·35 Å. for specimen R (56 % soda-felspar); the axial length diminishes continuously as the percentage of soda-felspar increases.

Similarly, rotation photographs of specimens I, J, K, and M about the *b*-axis show a single set of layer-lines, the additional reflections due to the soda-felspar lamellae in the untreated material having disappeared; with specimen R, the additional reflections are still visible, but they are relatively much weaker than in the corresponding photograph of the untreated material, and appear to indicate a smaller angle between principal axis b_1 and secondary axis b_2. (No additional layer-lines can be seen on *a*-axis photographs of this specimen.)

It seems clear that we are here concerned with two processes. In the first place the lamellae disappear, rendering the felspar optically homogeneous; this change presumably represents the consequence of diffusion of the sodium and potassium ions through the tetrahedron framework, and the gradually diminishing *a*-axis (in the treated materials) is a measure of the increasing importance of the small sodium ions in determining the dimensions of the structure. In the second place, some additional modification of the structure occurs which prevents the exsolution of soda-felspar and formation of lamellae, and is responsible for the striking change in optic axial angle. This change, it will be noted, cannot be due to the interdiffusion of sodium and potassium ions, since it is observed in specimens A and C (4 % and 9 % soda-felspar, respectively), which contain relatively few sodium ions.

Further work is needed to elucidate the nature of this second change, but we may point out that no marked alterations in axial length occur when specimens A and C are sanidinized, nor do the relative intensities of reflection suffer any marked alteration.

IV. Axial Lengths of Untreated and Homogenized Felspars.

In the preceding sections we have described qualitatively the changes observed when orthoclases suffer the specified heat-treatment. A quantitative discussion may be attempted, but it should be emphasized that the experimental method does not permit the attainment of great

ccuracy in determining axial lengths, nor does it supply any direct ieasurement of interaxial angles.

The individual measurements of axial lengths for untreated and homo-enized materials are collected in table I and represented graphically i fig. 1. The following conclusions may be drawn:

(i) *The* c-*axis.*—All experimental values for both untreated and reated specimens lie close to the simple mean $c = 7{\cdot}17$ Å. Specimens [and R, untreated and treated, may perhaps be exceptions: their oints lie below the mean at distances slightly greater than would be ttributed to experimental error.

(ii) *The* a-*axis.*—The length of the unique axis a of the homogenized iaterials diminishes steadily as the percentage of soda-felspar increases. 'he straight line YY' represents the variation of axial length with omposition, only one point (M treated) lying at a distance from the ne greater than that corresponding to probable experimental error.

For specimens A, C, D, E, F, G the lengths of the principal axis a_1 or the untreated materials also lie very closely on the same line, but for pecimens I, J, M, R (untreated) the values of a_1 lie quite away from the ne YY' and are all extremely close to a mean value $a_1 = 8{\cdot}635$ Å. For specimen K the experimental value is much lower than for J which as nearly the same composition: we assume that this discrepancy rises from some unexplained experimental error, and neglect K in nding mean values.)

The gradual decrease in length of the a-axis of the treated materials, ith increase of soda-felspar, might be anticipated; the abrupt change in ehaviour of the principal axis a_1 of the untreated materials, on passing com F to I, was not anticipated. The secondary layer-lines in a-axis hotographs are visible for specimen E (probably) and F (certainly), s well as for I, J, K, M, R, but additional reflections in b-axis photo-raphs (indicating a secondary axis b_2 not coinciding with b_1) appear or the first time in specimen I; these facts (already discussed in sec-ion II), considered in conjunction with the observed abrupt change in he magnitude of a_1, appear to indicate that the properties of the otash-felspar constituent of the perthitic structure are independent of he soda-felspar lamellae only when the amount of soda-felspar exceeds 1·5 % (specimen F).

(iii) *The* b-*axis.*—The significance of these measurements is less ertain than for the axes a and c, and the 'spread' of the experimental oints is wider. Of various possible interpretations the following appears o us to be the most probable (p. 348).

TABLE I. Axial Lengths and Densities of Untreated and Homogenized Felspars.

Specimen.	Symbol.	Composition by wt. %. Or.	Ab.	An.	Axial lengths (determined experimentally). Untreated. a_1	b_1	c_1	Homogenized. a	b	c	Axial lengths from graphs in fig. 1. a_1	b_1	Densities. Untreated. $D_{calc.}$	$D_{obs.}$	$(D_{obs.}-D_{calc.})$	Homogenized. $D_{calc.}$	$D_{obs.}$	$(D_{obs.}-D_{calc.})$
		%	%	%	Å.	Å.	Å.	Å.	Å.	Å.	Å.	Å.						
Madagascar yellow orthoclase ...	A	96	4	—	8·60	13·06	7·19	8·57	13·02	7·19	8·585	13·05	2·538	2·563	0·025	2·543	—	—
Burma colourless	C	91	6·5	2·5	8·60	13·02	7·22	8·60	13·03	7·16	8·56	13·03	2·546	2·563	0·017	2·545	2·555	0·010
Burma blue, no. I	D	84	14	2	8·52	12·96	7·17	8·52	13·06	7·16	8·53	13·00	2·559	2·567	0·008	2·543	2·555	0·012
Kalahandi orthoclase	E	83	15	2	8·52	13·01	—	—	—	—	8·525	12·995	2·560	2·570	0·010	2·543	—	—
Burma blue, no. II	F	78·5	19	2·5	8·50	13·07	7·18	8·49	13·04	7·15	8·505	12·98	2·569	2·571	0·002	2·542	—	—
Eifel sanidine ...	G	76	21	Ce 3	8·53	13·08	7·17	8·53	13·08	7·17	8·51	13·03	2·559	2·576	0·017	2·559	2·572	0·013
Ceylon blue, no. I	I	69·5	29	1·5	8·64	12·92	7·19	8·46	13·01	7·17	8·635	12·94	2·541	2·578	0·037	2·538	—	—
Ceylon blue, no. II	J	64	34	2	8·61	12·92	7·19	8·42	13·07	7·21	8·635	12·92	2·546	2·580	0·034	2·537	2·555	0·018
Burma blue, no. III	K	64·5	34	1·5	8·53	12·98	7·13	8·41	12·98	7·11	8·635	12·92	2·545	2·578	0·033	2·537	—	—
Ceylon blue, no. III	M	57·5	40	2·5	8·65	12·84	7·18	8·48	13·01	7·19	8·635	12·895	2·554	2·585	0·031	2·537	2·555	0·018
Fredriksvärn anorthoclase ...	R	44	51·5	4·5	8·64	12·87	7·12	8·36	12·82	7·12	8·635	12·84	2·566	2·595	0·029	2·537	2·569	0·032

The description of the specimens, the lettering, and percentage compositions, are taken from Spencer, 1937. The axial lengths and densities are discussed in detail in section V of the text.

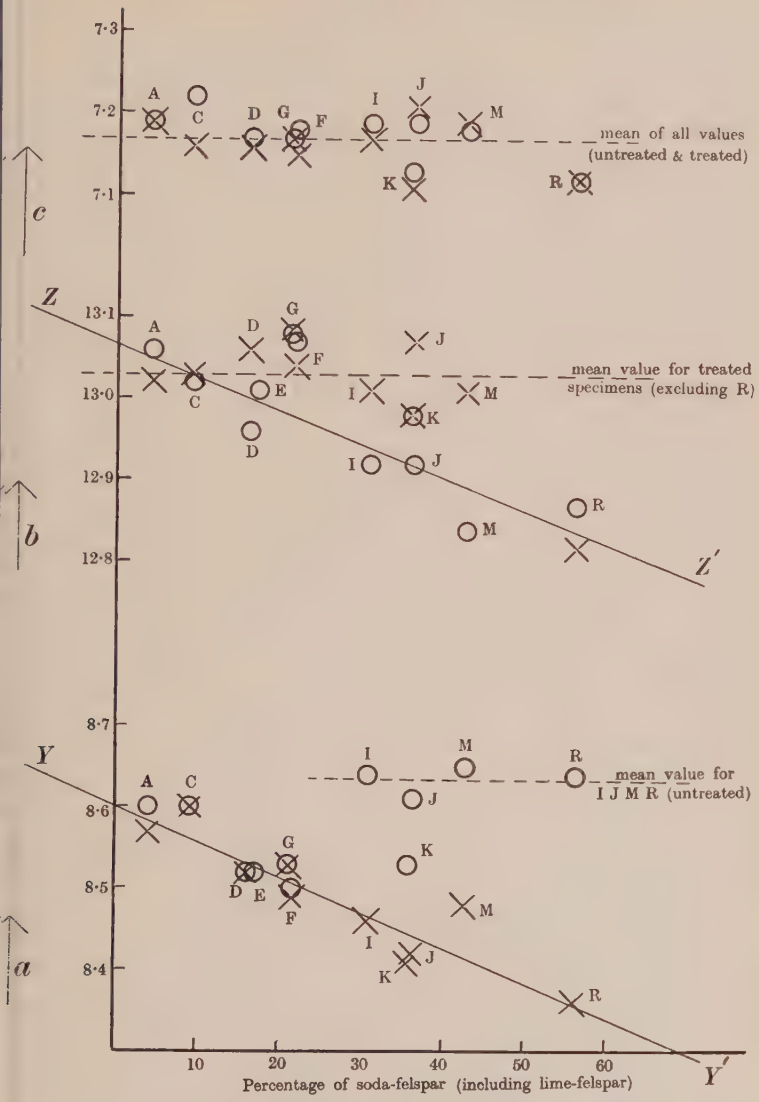


FIG. 1. Axial lengths of untreated and homogenized felspars.

The axial length in Å. is plotted vertically, the percentage of soda-felspar cluding lime-felspar) horizontally. Circles and crosses represent untreated and mogenized (treated) specimens respectively. The lettering of the specimens rresponds to that of table I.

For the homogenized materials A to M, individual values are grouped about a mean value $b = 13{\cdot}03$ Å.; for R the observed value $b = 12{\cdot}82$ Å. is markedly lower. This difference probably corresponds to the fact (discussed in section III) that in b-axis photographs of R (treated), additional reflections can be distinguished which are similar to those in photographs of untreated material, whereas in specimens up to M homogenization is apparently complete.

For the untreated materials, excepting F and G, the experimental values are grouped about the straight line ZZ'. Specimen G (sanidine) is naturally homogeneous, and would therefore be expected to conform to the law for *treated* materials, as in fact is the case. Specimen F remains as the only specimen showing unexplained departure from the variation law represented by the line ZZ'.

To test the correctness of the above interpretations of the experimental data we have calculated the densities of untreated and homogenized materials and compared these values with those determined directly. The results are collected in table I.

The procedure adopted in finding the density by calculation ($D_{\text{calc.}}$) is as follows. For specimens A and C (untreated), which are homogeneous, a unit cell with axes a_1, b_1, c_1, and angles $\alpha = \gamma = 90°$, $\beta = 64°$, is assumed to contain amounts of potash-felspar and soda-felspar, in the proportions given by Spencer's analyses, such that there are altogether 32 oxygen atoms per unit cell. For specimens D, E, F, I, J, K, M, R, (untreated), the potash-felspar and 8 % of the soda-felspar[1] are assumed to have a structure with a monoclinic unit cell a_1, b_1, c_1, β, and the remaining soda-felspar a structure with monoclinic unit cell a_2, b_1, c_1, β; the density of the microperthitic crystal is finally deduced by considering the relative amounts of the two structures present. Lime-felspar and barium-felspar are assumed to have the same structures as soda-felspar and potash-felspar respectively. The values $a_2 = 8{\cdot}12$ Å., $c_1 = 7{\cdot}17$ Å., $\beta = 64°$, are assumed throughout, and values of a_1 and b_1 appropriate to the composition of each specimen are deduced from the lines YY' and ZZ' of fig. 1.

For all treated specimens and for specimen G (untreated) a single monoclinic unit cell is assumed with axes $b = 13{\cdot}03$ Å., $c = 7{\cdot}17$ Å. $\beta = 64°$, and axis a deduced from the line YY'.

For the untreated specimens the observed densities ($D_{\text{obs.}}$) are taken from Spencer's data; we have determined the densities of six

[1] Potash-felspar may retain 8 % of soda-felspar in solid solution (Spencer, 1930 pp. 313, 330–331).

reated specimens by flotation in a mixture of chloroform and bromo-
orm.

It is clear from table I that all calculated densities are lower than the
orresponding observed densities; this is presumably due to a slight in-
ccuracy in the calibration of our apparatus. (It should be noted that
ach axial length a, b, c must be determined to 1 part in 750 if the den-
ty is to be accurate to 1 part in 250, i.e. if the difference $(D_{obs.}-D_{calc.})$
not to exceed $\pm 0{\cdot}010$).

For the untreated specimens A to G the difference $(D_{obs.}-D_{calc.})$
anges from 0·025 to 0·002, with a mean value 0·013; for untreated
pecimens I to R the difference ranges from 0·037 to 0·029, with a mean
alue 0·033. The abrupt change in passing from F to I is again evident
G is omitted from consideration of the series of microperthitic struc-
ures); the discrepancy between calculated and observed densities is
ncreased in specimens I, J, K, M, R because in making the calculation
monoclinic cell a_2, b_1, c_1, β is assumed, whereas the soda-felspar cell is
eally triclinic (see section II), and so for given axial lengths and given
ngle β is of smaller volume than the assumed monoclinic cell.

For the treated specimens, with the exception of G, all calculated
ensities are nearly identical, the actual figures showing a slight decrease
om A to R. By direct observation, the density is 2·569 for R, 2·572 for
, and 2·555 for C, D, J, M, which may be taken as representative of the
nge from A to R, excluding G. The high value calculated for G is due
the barium content of the specimen, and the observed value is corre-
pondingly high. The high value observed for R is probably due to the
bnormally short b-axis, 12·82 Å. against the mean value of 13·03 Å.
ssumed in calculating the density.

The general agreement between observed and calculated densities, for
oth untreated and treated specimens, encourages us to believe that our
ttempt to give a quantitative interpretation to the measurements of
xial lengths is based on something more than pure speculation, and that
he regularities which are apparent in fig. 1 are not due to coincidence
rising out of experimental inaccuracies.

V. Conclusion and Summary.

We have examined by X-ray methods a series of microperthitic
otash-soda-felspars of varying composition, in their normal state and
fter homogenization by prolonged heating at high temperatures. In
he untreated microperthite the crystal contains two closely related
tructures, one (containing the potash-felspar) being monoclinic, the

other (containing most of the soda-felspar) being triclinic but different from ordinary albite. In the homogenized specimens only one single structure is present. The cell-dimensions of both untreated and treated specimens depend in a rather complicated way upon the amount of soda-felspar present.

We wish to express our thanks to Dr. E. Spencer for the supply of materials, and for helpful discussion during the course of the work. One of us (S. H. C.) is indebted to the Government of Honan for the grant of a scholarship during the tenure of which this work was carried out.

Note on a specimen of white beryl from Beam mine, St. Austell, Cornwall.[1]

By A. F. Hallimond, M.A., Sc.D.

Assistant Curator, Museum of Practical Geology, London.

[Exhibited November 4, 1937.]

THE specimen, which is in two pieces cemented together, was purchased for the Museum of Practical Geology in February, 1888, from Mr. F. H. Butler, and bears the Museum's original Mineral Inventory label (M.I. 5714) on each portion. The inventory description is "Tinstone, well crystallised, coating granite, Beam mine, Cornwall". The exhibition label mentions quartz, and the presence of beryl had no doubt been overlooked through the general resemblance to milky quartz, which is not uncommon on some Beam mine material. Actually it was noticed during the rearrangement of the collection in 1934 that the cassiterite is accompanied by large, dull white crystals which proved to be beryl. In view of the rarity of beryl in Cornwall a brief description may be of interest.

A block of granite forms the back of the specimen: it is about $6\frac{1}{2}$ inches across, rich in quartz, with scattered crystals of sericitized felspar up to 1 inch in length, and closely resembles the altered wall-rock seen in other specimens from the Beam mine. One side has been the face of an open fissure, and is coated with cassiterite and tourmaline in the manner typical of this well-known locality.

The cassiterite crystals are black, about $\frac{1}{2}$ inch across, bounded by very short prism faces *m* with pyramids *s* and *e* (striated), and very small *r* faces. The crystals are twinned on *e*, resembling those from Zinnwald (Dana, System, 6th ed., 1892, p. 234, fig. 4). Among the cassiterite, and apparently deposited both earlier and later, are shafts and felted aggregates of black tourmaline, refractive index ω 1·66, particoloured brown and blue in crushed grains.

About twenty-five white crystals of beryl are implanted more or less parallel with the surface of the fissure. They enclose shafts of tourmaline, and are closely surrounded by cassiterite or occasionally by felted tourmaline, but their hexagonal outlines against the latter two minerals

[1] Published by permission of the Director, Geological Survey and Museum.

indicate that they are the earlier. The largest crystal is over 1 inch in length and $\frac{1}{3}$ inch in diameter. They are translucent and are bounded by a hexagonal prism and base, but the faces are more or less deeply corroded. Crushed fragments are transparent, but contain numerous microscopic hexagonal negative crystals with steep terminations and filled with liquid, usually accompanied by a gas-bubble. Refractive index (by immersion) 1·57, cleavage indistinct, birefringence moderate, optically uniaxial and negative, scratches quartz.

This appears to be the only record of beryl from the Beam mine; the large number of crystals and their even distribution over the surface would suggest that more material from the same fissure may have been preserved. Unfortunately the crystals are corroded, but in size and quantity they afford an interesting addition to the very few records of beryl from Cornwall.

The Huckitta meteorite, Central Australia.

(With Plates XII–XV.)

By C. T. Madigan, M.A., D.Sc., B.E., F.G.S.

With chemical analyses by A. R. Alderman, M.Sc., Ph.D., F.G.S.

Department of Geology, University of Adelaide.

[Read January 26, 1939.]

Discovery.

THE author arrived at Huckitta station, 135 miles north-east of Alice Springs, towards the end of June, 1937, on an expedition to e Tarlton Range at the north end of the Simpson Desert.[1] The anager of the station, Mr. W. Madrill, said that a half-caste named ck Laughton employed on the station had a stone he would like to ow, and this was produced by Laughton in the usual diffident manner the half-caste. It proved to be a flat, rusty mass weighing a little over ne pounds. A few knocks with a hammer soon showed it to consist in rt at least of malleable iron, and a meteorite was at once suggested. e specimen was not very closely examined, and the olivines, which ow up so excellently on the polished surfaces, were entirely overlooked, ich is quite easily done in the case of the iron-shale or the more eathered natural surface of the meteorite, although olivine makes up ore than half the volume. It was said that the specimen came off a stone which stood several feet out of the ground. One was inclined be sceptical, having had much experience of prospectors' and bush-en's tales, and as the place was comparatively inaccessible it was cided to visit it on the return journey in a fortnight's time, while in e meantime Madrill and Laughton should go out and peg the place as mineral claim and establish some uncertain sort of rights over the pposed meteorite, and get camels ready for the next journey. On the urn to Huckitta, all was found to be in readiness, and the trip to the teorite was made by camel.

[1] C. T. Madigan, The Simpson Desert and its borders. Journ. Roy. Soc. New uth Wales, 1938, vol. 71, pp. 503–535, map, 7 pls. Brief mention of the Huckitta teorite has been made in Trans. Roy. Soc. South Australia, 1937, vol. 61, p. 190.

A. 7–73.]

Huckitta station lies against the south side of the Dulcie Range, which is really a tableland of Ordovician sandstone about 30 miles wide east and west, and 15 miles through north and south, intersected by deep and narrow gorges. The meteorite was on the north side of the range. There are no motor-tracks round the range, and only bridle-paths through it, so it was thought to be quicker to go through by camel than to make a track round by car. The only map of this area is the sketch-map made by the late South Australian Government Geologist, H. Y. L. Brown,[1] in 1896. Brown admits getting lost in the gorges, and indeed it is very difficult to go through the range and make any sort of traverse without spending considerable time. Thus on emerging on the north side of the range one was not certain of the bearing of the station. A gorge discharging northward was entered a mile inside the southern front of the range. This gorge supplies a creek running north-eastward in the plain on the north side of the range, and to-day is called Ooratippra Creek, though probably not the Ooratippra Creek of Brown, for several creeks come out on the north side of the range. From the station to the Ooratippra waterhole 2 miles beyond the range was about 20 miles in a direction a little east of north, and from the waterhole the route lay along the front of the range eastward for 7 miles to Turkey Creek. The site of the meteorite was a couple of hundred yards off the left bank of Turkey Creek, and about 4 miles down the creek from the front of the range. It is in a cattle-mustering place, easily recognized from the bare and trodden ground. The position of the station house was determined by sidereal observations as 22° 35′ 00″ S., 135° 35′ 04″ E., and the position of the meteorite by dead reckoning from this place as 22° 22′ S., 135° 46′ E.

The meteorite in situ and the surroundings before anything had been disturbed are shown in fig. 1, with the station manager, Mr. W. Madrill, on the right, and Mr. R. L. Crocker, who accompanied the author, on the left. At first sight the meteorite was not impressive, except as being the only large stone in the vicinity. It was the usual dark red colour of all desert stones, and only on one side were there any signs of structure. This was the windward side, away from the camera in fig. 1, where the surface was more etched by sand-blast, and lighter-coloured nodules were visible. This surface is shown in fig. 3, pl. XII, and an enlargement of a portion of it in fig. 15, pl. XV. First glances were disappointing. The stone appeared to be a piece of ferruginous conglomerate. Further

[1] H. Y. L. Brown, Reports on Arltunga gold field . . . and explorations north-east of Hart's Range. . . . Geol. Surv. South Australia, 1897.

amination, and the use of the hammer, however, soon showed up the
n beneath the veneer of oxide, and the 'pebbles' were seen to be
ar minerals, in fact olivine, though the regular fractures at first
ggested an orthorhombic pyroxene.

FIG. 1. The Huckitta meteorite in situ.
(*C. T. Madigan, photo.*)

The story of the discovery of this stone as a meteorite throws interest-
g light on the characters of both the black man and the white, and
rticularly of both of them as combined in the half-caste. Madrill was
y much interested to hear the truth, for it appeared clear that none
d thought of a meteoritic origin. He said that he had camped by the
ne at mustering times at least once a year for the past ten years. It
s a landmark for the cattle camp. There are few cattle yards in this
untry. The cattle are merely rounded up and 'held', and the stone
s on the edge of the bare area where the cattle are bunched. Stockmen
le round the cattle all night, usually singing or whistling, to prevent
y sudden noise alarming the beasts and causing a stampede. Madrill's
stom was to ride round the side remote from the camp, leaving the
mp side to an aboriginal. At this place the camp was always by the
ne, and he had noticed that the native invariably chose to ride on
e far side, away from the stone, a thing he had wondered at but never
estioned, as the natives have many quaint customs and taboos that

mean a lot to them and which it is not only unkind but bad policy to interfere in. The whole thing was now clear to Madrill. The natives held the stone in awe, probably as a sacred and therefore fearful thing. The black man knew the stone was something strange, the white man was quite indifferent to it, but the half-caste, Mick Laughton, had the minds of both. He knew the blacks' point of view, but did not fear the stone. He broke a piece off and brought it into the station to find out all about it when some one with the required knowledge should come along, no doubt in the hopes that it might prove of some value, as indeed it did, for eventually he and Madrill each received a hundred pounds in cash.

The meteorite lay in a slight depression in the sandy and gravelly plain, resting on shaly material. We decided to remove the mass from the hole and discover what lay beneath. It could easily be rocked with a bar, but it weighed nearly a ton and a half, and was no light task to move in the sandy soil with the means then available; in fact, this took two of the party half a day, without the aid of Madrill, who had gone after the camels which had strayed away during the night. Having got the main mass clear of the hole, digging was begun with pick and shovel. It was soon clear that there was very extensive iron-shale under the iron mass, in fact that the piece removed was merely the kernel of the original meteorite, the oxidized portion above ground having been removed by erosion, but that below ground being entirely preserved. Digging in the sandy gravel was extremely difficult and slow. An attempt was made to get to the bottom of the iron-shale on one side, and a trench was dug 2 feet 4 inches deep, with the shale still going down. Madrill had to get away to go on with a cattle muster that was in progress in the vicinity, and so it was decided to give up what was with inadequate tools obviously several days' work, and to send a party out to excavate all the iron-shale, which was eventually done under Madrill's supervision. The author agreed that Madrill and Laughton should consider themselves owners of the meteorite, and that he would seek funds to have the whole of the material brought to Adelaide and finally purchased by some institution, the proceeds to go to them, and he reserving the rights of description. The University of Adelaide advanced the funds for the transport to Adelaide, and Mr. W. Burdett of Basket Range secured the meteorite for South Australia by buying it and presenting it to the South Australian Museum. The party that brought the meteorite to the railway at Alice Springs took several weeks over the job, and had some difficulty in getting it on to the motor truck, in addition to breakdowns on the way.

Description of occurrence.

The disposition of the meteorite resembled very roughly that of a thick at-iron resting on one side, the point down, and the whole slightly tilted deways. It was tilted forward on its point, which was the lowest part nd buried to a depth of only 8 inches, so that almost the whole of the ass was showing above ground. Towards the other end it was resting n iron-shale. It was of a dark red colour, being thinly coated with rust, ith a rough but uniform surface. Only on one side, exposed to the ind and sand, did any inclusions show up. There the olivines could be early seen, being of lighter colour, and though at first one might have pected them to be projecting the reverse was the case, for these areas ere slightly hollowed out, due to the cracking up of the olivine under eathering conditions. On other sides the olivines too were very rusty n the outside, and not at all readily distinguishable. In fact, the sur- ce mainly looked quite uniform, and even when struck with a hammer ere was little indication that half the stone was olivine. The largest vine exposed was $2\frac{1}{2}$ by $1\frac{1}{2}$ inches, while equidimensional grains of inch in diameter were plentiful. One narrow fragment was 3 inches ng.

The meteorite stood in a slight depression on the plain of sandy gravel, in what might be described as a very shallow crater with a distinct (fig. 2). The rim stood about 5 feet from the meteorite, and the level side the crater was 7 inches below the rim, the outside ground-level ing 5 inches below. The crater was distinctly elongated in the direc- n of the long axis of the meteorite, and the direction of this axis was ° north of east, in which direction the sharp end or nose of the eteorite pointed. The meteorite was not exactly in the middle of the ater but distinctly towards the eastern end, with a shallow groove rough the rim of the crater at the western side. This gave a definite pression that the meteorite arrived from the west travelling east, or ore exactly E. 16° N. Small oxidized fragments were found plentifully the surface all round to a distance of 40 feet. These are more likely be pieces weathered off the main mass and scattered by wind and od and cattle, than to be parts of the original fall.

The iron-shale was found on excavation to extend down about 3 feet low the meteorite. The river wash of sand and gravel underlay the n-shale. No bedrock is anywhere visible in the neighbourhood. The an of the body of iron-shale was roughly a triangle with a length 8 feet and width of base of 7 feet 2 inches, with the apex of the

triangle pointing eastward. These dimensions are more than double those of the kernel, so that it is obvious that the meteorite was originally at least eight times the size of the kernel and must have weighed over 10 tons. The shape of the accumulation of iron-shale, indicated by dotted lines in fig. 2, conforms to the shape of the kernel.

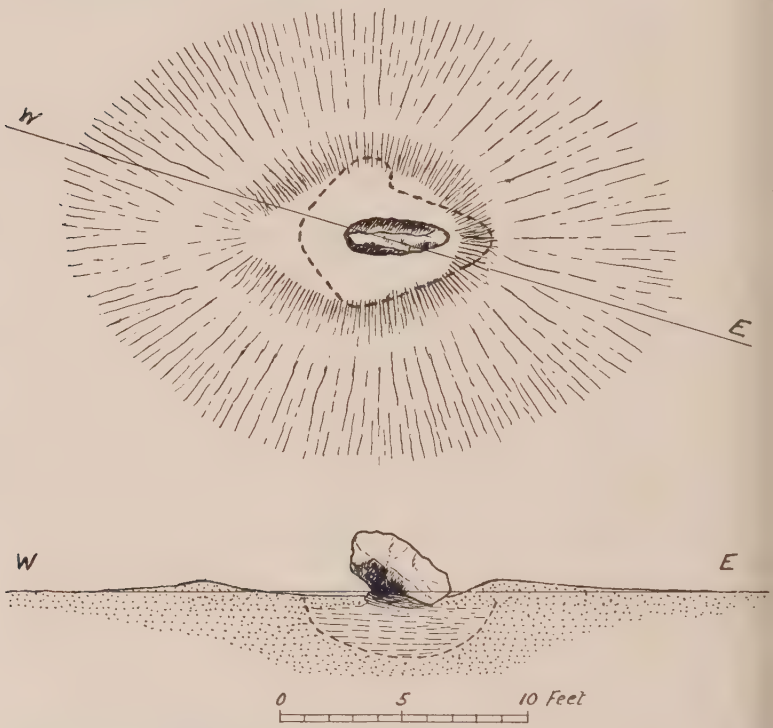


Fig. 2. Plan and section of the Huckitta meteorite in situ. The dotted line shows the outline of the iron-shale after excavation.

The iron-shale was removed and bagged and sent to Adelaide, but the final excavation was not seen by the author. It was fairly coherent and broke under the pick in pieces of dimensions up to 2 feet and weighing up to 300 lb. Ten ore-bags each containing about 50 lb. of smaller fragments were sent down, with three large pieces weighing 289, 247, and 111 lb., and nine smaller pieces from 50 to 100 lb. The total weight of iron-shale received was 2040 lb., which is not consistent with the size of the excavation. Probably a good deal of material was broken fine and discarded.

Dimensions, weight, and specific gravity.

The longest dimension of the meteorite was 4 feet 5 inches, along the de shown in fig. 3, pl. XII, and the greatest girth 7 feet 4½ inches, near e wide end. The greatest depth was about 3 feet, and greatest width foot 4 inches. The weight of the kernel or main unweathered mass was con 7 cwt. 3 qr. 4 lb., or 3112 lb., or 1415 kilograms; and that of the n-shale brought in was 18 cwt. 24 lb., or 2040 lb., or 927 kilograms. The specific gravity was determined on the end-piece that was cut off, ing a beam balance weighing 100 lb. to quarter ounces, borrowed from scale-making company. The piece was weighed in air and water, the ight in air being 93 lb. 15¼ oz. The specific gravity thus determined s 5·073.

Cutting and polishing.

The small piece first shown by Laughton was rubbed down and lished by a monumental mason before the arrival of the main mass. is showed the coarse pallasite structure for the first time, and one lized what a wonderful effect the polishing of a larger area was going make. The olivines, brown to green, stand out in their white setting iron, like jewels set in platinum. The masons made light of the task of lishing iron, but to their amazement it took three weeks on a table fed h steel sand or shot to level off the small piece that was already sonably flat. The malleable iron does not respond to this method of nding like the brittle minerals of granites which are very quickly ound down. By comparison, the action of emery-wheels is rapid, small gments of the meteorite being soon smoothed off on them. A cutting ion is necessary, by material or particles firmly held, not rolling sely as in building-stone cutting and grinding.

The South Australian Government Railway workshops at Islington, ar Adelaide, undertook to cut the main mass of the meteorite after perimenting on the small piece with a small diamond disk-saw, and it s done by the tool-room foreman, Mr. H. W. Rossiter, under the ection of Mr. F. H. Harrison, works manager. First the small end the meteorite was cut off, a cut of maximum dimension 18 inches, wn in fig. 4, pl. XII; and when this was successfully done, the broad e forming half the side shown in fig. 3 was attacked and a thin slab s cut off parallel to the face, a piece nearly 4 feet long. This slab was hly polished, but the face remaining on the meteorite only moderately on account of difficulty in handling. These two cuts were at right

angles to each other. The structure and arrangement of the olivines showed no appreciable differences in the two cuts.

The iron disk-saw specially made for the job was 4 feet 6 inches in diameter and $\frac{5}{16}$ inch thick. Diamond chips embedded in little copper cylinders were driven into drill-holes round the rim at 6-inch intervals, and in between each pair of diamonds two chips of the special lathe-tool facing material known as widia were inserted, making 24 diamond chips and 48 widia chips. The widia chips were about $\frac{1}{8}$ inch in diameter, and the diamonds much smaller. They were all staggered from side to side of the disk. The cutting speed was 15 revolutions a minute, and the average cutting-rate was from $\frac{1}{4}$ to $\frac{1}{12}$ inch per minute. The small end, of greatest width 18 inches, took $12\frac{1}{2}$ hours to cut through. The meteorite was fed up to the saw, as in timber sawing, and was continually moved so that the saw was never cutting a face of more than a few inches in length. At the beginning the widia chips were standing 'proud' of the diamonds, but eventually they wore down to the same height, and some came out occasionally. In Mr. Harrison's opinion the diamonds eventually did most of the cutting, but the extent of their relative action remained uncertain. These details are given, as the cutting of a pallasite presents great and unexpected difficulties. The iron alone or the olivine alone would prove a much easier proposition. It is the combination of a comparatively soft and malleable metal with a hard but brittle mineral which creates a problem, and the combination of widia and diamond in the cutting-tool seems a very satisfactory solution. Fortunately the railway workshops had abundant diamond rejected from emery-wheel facing operations.

Several smaller pieces were ground down on emery-wheels to which the material responded comparatively readily, producing a handsome surface with white iron and gemmy olivine. High polishing was found to make the iron greyer. The surfaces exposed by the two railway workshops cuts were roughly polished at the shops, but not highly enough to show any structure or respond to etching. These large surfaces, however, make magnificent museum exhibits. The end-piece weighing 94 lb. (fig. 4) was further polished by the author, by first rubbing down by hand with a small cylinder of cast iron grooved on the face, with successively coarse to the finest emery-powder, and finished off with a portable buff on a flexible extension from the ordinary polishing buff shafting, using Canning's tripoli lustre compound. This was a very slow process over an area of 16 by 11 inches. Some granulation of the iron was visible under the higher polish, but very little structure was shown until the surface

as etched with a 10 % solution of nitric acid in alcohol for about one inute. The iron was then seen to be made up of rounded kamacite ains, and angular interstitial plessite surrounded by a bright narrow enite border; the kamacite grains quite featureless, but the plessite owing some cloudy lines.

A small fragment (fig. 9), a little over an inch long, was polished as ghly as possible by ordinary methods, as it could be held in the hand d etched in the same way, with slightly better results, as Widmanetter figures appeared rather nebulously in the plessite.

An attempt was made by a stone-mason to cut through a piece of the n-shale, 8 by 6 inches, with a small emery-disk. This material proved en more resistant than the unweathered meteorite, as the iron oxides re much harder than the iron alloys. A hack-saw will make no impresn on the iron-shale. The mason succeeded in making two cuts 8 inches ng by 2 inches deep, one on each side of the lump, and then broke ough the remainder. The cutting had put quite a fair polish on the es. A portion of one of these cuts is shown in fig. 13.

Examination of the polished surface.

Most of the detailed work was done on the face of the 94 lb. piece own in fig. 4. The surface measures 16 by 11 inches. Before etching, ly olivines and iron were visible, together with numerous small yellow ins mainly in contact with the olivine.

Proportion of iron to olivine.—The relative amounts of olivine, iron, d yellow grains were estimated on the Rosiwal method by ruling off ith a pencil ten lines an inch apart across the slab. These lines were m 13 to 16 inches long, and the measurements were made under a ns with a scale divided to sixty-fourths of an inch and read to halfvisions. Actually a length of 12 feet 10 inches was measured in this ay, and the proportion of olivine to metal was found to be 1·38 to 1, 58·0 % olivine by volume. The area of yellow grains was 1 % of e whole or 2·6 % of the total metal. The estimate of yellow grains is ugh, as many particles were too small to measure with any accuracy, nd approximations had to be made. However, considering the distance easured, the figure has some value.

The olivine.—The shape of the olivines is definitely fragmentary. The ppearance of the fragments of a crushed grain of olivine under the icroscope is exactly that of the olivines in a section of the meteorite. hey are angular, often with straight sides, and frequently running to harp points. There is no suggestion of crystal form, or of any roundings,

fusion, or absorption. They are all traversed by numerous fractures, often in one or more parallel sets suggesting cleavage macroscopically, but with much less regularity under the microscope. The colour is brown to green, but colourless under the microscope. The brown colour is due to iron oxides spreading into the cracks from the iron, not from decomposition of the olivine, which is very fresh. Some larger olivines on the outside are very brown, but green also occurs in the peripheral regions. The colour seems to depend on the degree of fracturing. Small grains are clear, and all is colourless in thin section. The average width of the 468 olivines measured in the Rosiwal determination was $\frac{3}{16}$ inch or 4·8 mm., but many on this slab had measurements of 1 inch, and three pieces of 2 inches.

Only very exceptionally is any iron included in the olivine areas on the polished slab, so rarely as to suggest re-entrant angles in the olivine or separate fragments of olivine surrounding the iron. It can be seen in only five places on the slab shown in fig. 4. Olivine and troilite, on the other hand, are often intimately intermixed, as described below.

Fragments were chipped out of five olivines on the slab measured, for examination and chemical analysis. It was soon seen that the cracks in the olivine were filled with iron oxide, so that most fragments could be picked up with a magnet, and fine crushing and hand-picking was necessary to select material for analysis. Under a strong lens some of the olivine was seen to contain a few inclusions of very fine parallel needles.

The specific gravity, determined by flotation in Clerici's solution, is 3·38, indicating an olivine towards the forsterite or magnesian end of the series. The green grains from all crystals were of the same gravity, but the browner ones were a little lighter, due no doubt to fissuring, but the differences were not measurable. The average refractive index is 1·67, and the grains are optically positive, with an axial angle approaching 90°, $r > v$. In a thin section the olivine areas were all individually in optical continuity, that is, parts of single crystals and not aggregates of grains; the edges are clean cut, and there are many fractures but no cleavage. The grains readily gelatinize in hydrochloric acid.

The nickel-iron.—The structure of the nickel-iron is well seen in figs. 5–12. On etching, the white iron readily resolves itself into white grains of kamacite, rounded and irregular and structureless, enclosing darker interstitial areas of plessite of angular and embayed form. All plessite areas are edged with a bright white line of taenite which appears white in some of the photographs, dark in others, depending on the incidence of the light. The taenite bands have a sharp border on the

tside towards the kamacite, but fade on the inside into the plessite; rrow parallel bands of kamacite frequently cross the plessite areas, as ll seen in figs. 6 and 8.

The dark line demarking the kamacite grains is due to oxidation reading between the grains. This oxide was more easily soluble, leav- a minute crack after etching, so that in passing outwards from a ssite grain one encounters first the taenite border standing well out, en a dark crack, beyond which the white kamacite sharply begins. e largest kamacite grains are 12 mm. across, most are 2–3 mm., and v under 1 mm. The mean of 39 measurements was 2·1 mm.

The interstitial plessite is in long and narrow forms. The greatest nensions are about 9 mm. and the average 2 mm. The taenite borders about 0·05 mm. wide. The kamacite grains surround the olivine; e plessite is everywhere remote from the olivine, and to be found in e middle of the nickel-iron areas. Structure in the plessite is not well rked, but Widmanstetter figures are quite distinguishable. The struc- re is usually not evenly distributed over the area, but is patchy, owing to the unaided eye as white cloudy areas in the plessite. This indicated in figs. 10 and 12.

Oxidation of the iron alloys has been most active in contact with the vines, some of which are surrounded by a dark band of oxides. In ny cases these bands extend across the iron areas and connect up the ger olivines where they are close together. Brassy grains are very nspicuous in these bands of oxides, particularly round the olivines. e oxidation effects were much more obvious in the small fragment own in pl. XIV, a piece knocked off the outside of the meteorite, than the sections of the main mass seen in pl. XIII.

The nickel-iron for chemical analysis was obtained by boring in the ger iron areas. This was done with a $\frac{5}{32}$-inch drill in a drilling chine. The smallest olivines are capable of stopping the drill. In all holes were drilled, but the deepest was only $\frac{3}{8}$ inch, and few of them nt more than $\frac{1}{8}$ inch. Owing to the necessity of avoiding the olivines, se borings would contain little if any of the yellow grains mentioned ove, which keep to the borders of the olivine.

Troilite and schreibersite.—The yellow or brassy grains showing on lished surfaces, which were found by the Rosiwal measurement to ke up 1 % of the whole volume of the meteorite, were very difficult determine, and much time was spent on them by the author with the d assistance of Mr. R. G. Thomas, Dr. A. R. Alderman, and Mr. D. C. digan. The varying results given by these chemists soon convinced

the author that there was more than one mineral represented by the brassy grains, which had at first been assumed to be all troilite. The brassy minerals occur in two ways, in part intimately and finely intergrown with olivine in chondrule-like masses, described below, and in part as separate grains, almost invariably in contact with olivines, and frequently forming a connecting link between adjacent olivines. The 45 grains measured in the Rosiwal determination gave an average width of 0·036 inch or 0·9 mm. The largest dimension being 2·8 mm. Thus all physical work on the grains had to be done under a lens. A quantity of material was obtained for examination by gouging out the grains with a magnetized needle, assisted by a spike and small hammer. All the brassy material was brittle, magnetic, and fusible to a magnetic globule. There was little to distinguish the grains in colour or hardness. The first difference noted was in fusing under the blowpipe. Even with the small particles available, it was found that some fused quickly and readily, while others jumped away. The latter were readily soluble in hydrochloric acid with evolution of sulphuretted hydrogen, and a few particles heated in an open tube gave off abundant sulphur dioxide. The material of these grains was then realized to be softer and more bronzy in colour than other particles. The former were found to be very difficult to get into solution. Preliminary tests by boiling material containing the grains with strong nitric acid gave negative results for phosphorus on addition of ammonium molybdate, but it was found that the brassy particles were not dissolving. Fusion with acid potassium sulphate, on the other hand, invariably lead to a convincing test for phosphorus. These grains required prolonged boiling and standing before they could be brought into solution with nitric acid, when the phosphorus reaction was strong. Some of these grains gave a positive reaction for sulphur, others a negative, but the sulphur was never in any considerable amount. After treatment with acid the grains became more tin-white than brassy in colour. Thus it was concluded that all the brassy material intergrown with olivine, and also some of the separate grains, are troilite, and the remainder and majority of the separate grains are schreibersite. Troilite is probably intergrown with schreibersite to some extent, for it was noted that some schreibersite grains effervesced slightly and even broke up when first treated with acid, after which further solution was slow and difficult. Also, some grains which gave a strong phosphorus reaction gave a weak sulphur reaction, in other cases no sulphur reaction. Probably about half of the yellow grains are troilite and half schreibersite. Cohenite was ruled out owing to its infusibility. These tests indicate that

ilite may be quite strongly magnetic, and that schreibersite is only uble with difficulty in nitric acid, and, in spite of its brittleness, has a rdness less than the 6½ usually quoted, for it can be scratched without at difficulty with a needle.

Chondrules.—A unique feature of the meteorite is the chondrule-like as shown in figs. 5, 7, and 8. These are of fairly uniform size, from an h down to half an inch across. Eleven of them appear on the slab wn in fig. 4, of which three are marked off and enlarged in pl. XIII. ey consist of aggregates of olivine and troilite in approximately equal ounts, the grain-size of each being small, the larger ones of the order millimetre. Some of the chondrules have the appearance of a eutectic stallization of olivine and troilite, as fig. 7. At first sight they appear be normal crystals of olivine, but under a pocket lens the vermicular ssy troilite is easily distinguished from the green olivine. In other es, as in figs. 5 and 8, chondrules are broken up round the edges into arate grains, embedded in the nickel-iron. It is then notable that the ilite never occurs as separate grains, but always in contact with an vine grain, while olivine grains may be separate. In the chondrules olivine is more granular, the troilite more attenuated and appearing erstitial towards the olivine.

Lawrencite.—The presence of this mineral was shown by the appear- e of green drops of liquid on the polished surfaces within a few hours olishing. They soon turn brown. The drops appear along the fissures arating kamacite grains, and particularly round the rims of olivine gments, between the olivine and kamacite. The larger fissures or k lines, made up of obvious iron oxides and often containing un- ered schreibersite in the oxides, are particularly prone to show the rencite, especially round or near the olivines. Even under a heavy ting of lacquer, brown vermicular lines of what is assumed to be ric chloride and limonite spread out over the white iron surface.

The iron-shale.

The iron-shale consists in the main of brown iron oxides of undeter- ned composition, but strongly magnetic and enclosing the unaltered vine. The meteorite has not disintegrated, the iron has merely dized. The appearance of polished surfaces is the same as those of unweathered mass, except that what was white iron is now dark wn, and the olivines are more cracked and shot through with lines ron oxide. This is well shown in fig. 13, where the dark iron oxides k white owing to the polish and reflection. The iron oxide portion,

in addition to being strongly magnetic, gives a brown streak, and is to some extent hydrated, giving off water in a closed tube and turning black. From its appearance its composition is not uniform, but probably a mixture of magnetite, haematite, and limonite. It varies in colour from reddish patches to dark brown and black. In thin section the olivine is quite clear, with sharp edges, but ramified with cracks filled with iron oxide. Fig. 14 is a photomicrograph of a thin section by transmitted light.

A closer examination of a large polished surface of iron-shale shows some bright spots. These are of taenite and schreibersite, unaltered by the weathering. The taenite is seen as thin bands enclosing areas which were once plessite, exactly as in the unaltered portions, but in addition there are odd grains 2 inches or so apart. No such grains of taenite were identified in the polished surfaces of the main mass. They are there probably indistinguishable from the enclosing kamacite, but in the shale they stand out conspicuously on the dark ground. Unlike the schreibersite, they are definitely remote from olivine grains. The largest grain is $\frac{3}{32}$ inch across or 2·4 mm. The schreibersite grains appeared in contact with olivines, just as in the unweathered mass. The taenite and schreibersite are easily distinguished in the polished iron-shale, the taenite being soft, smooth, white, and easily marked with a needle, while the schreibersite is brass-coloured, with rougher and granular surface, hard and brittle, and fragments may be detached with a magnetized needle to which they adhere. Tests of the brassy grains gave abundant phosphorus and only a trace of sulphur, indicating that troilite does not survive in the iron-shale.

In major cracks in the iron-shale occur small quantities of a green, minutely mamillated mineral that effervesces with acid, most probably the emerald nickel-bloom, zaratite. Fracture faces of shale frequently show a yellow-green filmy incrustation of this mineral.

The whole of the material below ground-level was oxidized to iron-shale, and contained no metallic iron. The line between the kernel and the shale was remarkably sharp, the kernel being easily rolled off the underlying shale, as described above.

Weathering.—There were only a few small pieces ready to flake off the main mass of the meteorite, although it took much hammering and baring to remove them. It was rather remarkable that the surface did not appear more shaly. Before the meteorite was left behind after its discovery it was only possible to remove a handful of chips, and the remainder was then as smooth and proof against attack as an anvil. One such chip is shown in fig. 9. It naturally shows more weathering effects

an the main cut. This piece was more highly polished, and the plessite en showed Widmanstetter figures as in fig. 10. The enlargements of rtions of this surface show the method of progress of oxidation in the larging of the lines separating the kamacite grains. In fig. 10 the ntral plessite grain has indistinct borders of taenite which enlarge into o grains of taenite on the right and left sides. Oxidation has gone on ry markedly along the upper right margin of the plessite, showing as lark band between the taenite border and the white kamacite. Some hreibersite granules can be seen in the oxidized band between two macite grains to the right. In fig. 11 schreibersite shows up very well its typical development in contact with olivine, with a larger area oxidized material beyond it extending in strings outward between macite grains. The weathering is always most marked round the vines, which in the more weathered material are surrounded by a band oxides with veins running into the olivine. This makes the olivines own coloured in the iron-shale, but the colour is entirely in the cracks. g. 12 shows a typical arrangement of grains with a band of oxide, and reibersite extending upwards from the olivine on the left.

Chemical composition.

The olivine and the metallic portion were analysed by Dr. A. R. Alderan with the following results, to which are added for comparison M. H. Hey's analyses of the Alice Springs pallasite.:[1]

	Olivine.			Metallic portion.	
	Huckitta.	Alice Springs.		Huckitta.	Alice Springs.
O_2 ...	40·21	37·24	Fe	89·36	92·28
O_3 ...	nil	nil	Ni	8·98	7·27
O ...	12·57	16·92	Co	0·45	0·20
O ...	nil	—	S	0·02	0·21
O ...	47·49	43·88	P	trace	nil
O ...	0·20	1·26	C	0·13	—
			SiO_2 and insol.	0·47	—
	100·47	99·30		99·41	99·96
O : FeO (mol.)	6·8	4·6	Fe : Ni (wt. %)	9·95	12·7
gr. ...	3·38	3·41	Sp. gr. ...	7·63	7·87

The carbon determination was kindly done by Mr. T. W. Dalwood in e Assay department of the South Australian School of Mines. Mr. R. G. omas found no reaction for the platinoid metals by ordinary chemical

[1] L. J. Spencer, A new pallasite from Alice Springs, Central Australia. Min. g., 1932, vol. 23, pp. 38–42.

methods in a 5-gram sample of the metal. The olivine is seen to be similar to the average composition of the olivines in pallasites given by P. N. Chirvinsky,[1] being 1·5 % richer in MgO than the average, and of identical specific gravity with the average (3·38). The analysis of the nickel-iron portion also agrees with Chirvinsky's average, being a little lower in nickel (0·82 % lower) and notably lower in sulphur, phosphorus, and carbon, for which elements Chirvinsky gives 0·17, 0·14, and 0·31 %. In the case of the Huckitta meteorite, as explained above, the troilite and schreibersite are closely associated with the olivine, and thus the borings, made in metallic areas as far as possible from the olivine, avoided these minerals, and the assay would necessarily be lower in sulphur and phosphorus than a true sample of the metallic portion of the meteorite. The yellow grains of troilite and schreibersite made up 2·6 % of the volume of the metallic portion from linear measurements. The 0·02 % of sulphur in the analysis, if all allotted to troilite, would give 0·055 % by weight or 0·09 % by volume of troilite in the metallic portion, a very much smaller quantity than the linear measurements suggest. If half the yellow grains were troilite, or 1·3 % by volume, this would give a sulphur percentage of 0·29 in the metallic portion. Similarly, if half the yellow grains were schreibersite, or 1·3 % by volume of the metallic portion, this would give 1·19 % by weight of schreibersite and 0·18 % of phosphorus, against the nil return of the assay. It is probable that the bulk composition of the non-olivine portion should contain somewhere about 0·3 % of sulphur and 0·2 of phosphorus.

The carbon has not been allotted to any mineral. No carbon nodules or carbides were identified, though cohenite may be present. On dissolving the metallic portion in acids light particles are seen floating which may be carbon or sulphur.

Specific gravity determinations on the metallic portion gave variable results. Fine borings as used in the assay gave 7·57 by the pyknometer method, using carbon tetrachloride. Another determination on the same material, using benzene, gave 8·40, which was discounted. Pieces of metal were then chiselled out of the edge of the meteorite where the two cuts meet and hammered to remove olivine. These pieces weighed about half a gram each; 4·8 gm. of them gave a specific gravity of 7·54 with the pyknometer and water. The same pieces were then tried on a Jolly's balance and gave 7·63. Nine pieces, including some larger ones that would not go in the pyknometer, gave 7·71 on Jolly's balance, and two

[1] P. N. Chirvinsky, Pallasites. Bull. Inst. Polytechn. Don, 1918, vol. 6, sect. 2, supplement. [M.A. 2–83.]

nuggetty pieces 7·70. Jolly's balance seemed to give higher results, but nly in one case was the material exactly the same. The mean of these ve determinations is 7·63, which figure is adopted as the specific gravity f the metallic portion. It is lower than Chirvinsky's average, 7·70.

From the specific gravity figures, 6·073 for the whole meteorite, 3·38 or the olivine, and 7·63 for the metallic portion, the proportions of livine by volume is 60·2 % and by weight 40·1 %. From the linear Rosiwal) measurements the proportion by volume of olivine to iron was ·38 to 1, or 58·0 % by volume, which gives, using the same specific ravities, 37·9 % by weight, a reasonable agreement.

Bulk composition.—Recalculating the analyses of the olivine and of ne metallic portion to 100 %, omitting the SiO_2 and insoluble portion in ne metal analysis and using the weight percentage of olivine (40·1 %) alculated from the specific gravities, the bulk composition of the eteorite is given below under I. For comparison: II, the bulk composi-on of the Alice Springs pallasite; and III, Chirvinsky's mean for 17 allasites.

	SiO_2.	FeO.	MgO.	CaO.	Fe.	Ni.	Co.	S.	P.	C.
I.	16·04	5·01	18·95	0·08	54·12	5·44	0·27	0·01	trace	0·08
II.	15·02	6·82	17·69	0·51	55·35	4·36	0·12	0·13	nil	—
III.	19·19	7·02	22·40	0·02	45·53	5·02	0·28	0·09	0·07	0·16

e olivine percentage for the Huckitta pallasite puts it in the olivine-oor group in Chirvinsky's classification, between Brenham Township nd South Bend.

Conclusion.

The Huckitta pallasite is particularly remarkable for its size. It is uch the largest so far discovered, being twice the size (about 700 kg.) f the original pallasite (Medvedeva = Krasnoyarsk) found in Siberia in 749. In the size of olivine crystals it is also outstanding. It is extremely milar to the Alice Springs pallasite described by Spencer. This frag-ent, weighing about 2 lb., was found on the Burt Plain by Dr. H. asedow, on the road from Huckitta, but over a hundred miles from the te of the Huckitta meteorite. The specific gravity of the two are almost ne same, the photographs of polished sections practically identical, nd the relative volume of olivine by linear measurements is exactly the me, namely 58 %. The analyses, however, differ somewhat, and more idely than the limits of error should cover, both as to the olivine and ne metallic portions. The molecular ratio of MgO to FeO in the Alice prings olivine was 4·6 against 6·8 in the Huckitta, and the 92·28 % iron

in the metallic portion with Fe:Ni ratio 12·7 in the Alice Springs, against 89·36 % iron and Fe:Ni ratio 9·95 in the Huckitta. Considering the differences in size, and the possibly larger quantities dealt with in examining the Huckitta meteorite, particularly in sampling the iron portion, it seems very probable that the Alice Springs pallasite is a piece off the Huckitta mass, carried by stockmen or natives, and eventually thrown away, a very common happening.

Explanation of Plates XII–XV.

The Huckitta meteorite, Central Australia.
(Photographs by H. E. E. Brock.)

Plate XII, Fig. 3. The meteorite at the Adelaide University propped up as it stood in situ. Viewed from the opposite side to text-fig. 1. The measure is a foot rule. Part of the area outlined is shown enlarged in fig. 15.

Fig. 4. Mass weighing 94 lb., cut off the end of the meteorite, just to the right and parallel to the end of the rectangle marked on fig. 3. Roughly polished, not etched. The areas marked on this face are enlarged in figs. 5–8. $\times\frac{1}{4}$.

Plate XIII, Fig. 5. Enlargement of the top left-hand marked area in fig. 4. The lightest areas are kamacite as roundish grains separated by dark lines and enclosing angular areas of darker plessite, which are surrounded by a white line of taenite. The large and darkest areas are olivine. The central chondrule-like mass consists of an intimate mixture of grains of olivine and troilite, the latter being lighter in shade, about the shade of the plessite, of which there is a large central grain. A larger rectangular crystal of olivine makes contact on one side with the central grain of plessite, but the remainder of the dark continuous mass in the centre is made up of small grains of olivine enclosed in troilite. Towards the periphery the mass is broken up into scattered grains of olivine embedded in kamacite. Some of the scattered grains are composite, with olivine and troilite, as the large one near the top, but the smaller ones are of olivine only, with no separate troilite grains. Polished and etched. $\times 2\frac{1}{4}$.

Fig. 6. Enlargement of the lowest marked area on fig. 4. This is the largest area free of olivine on the slab. The kamacite grains are well marked off, with the irregular interstitial plessite areas of darker tint surrounded by their rims of taenite, which here appear in part as dark lines owing to different incidence of light. Bands of kamacite are seen crossing some of the plessite areas, as in the centre. The darkest areas are all olivine. Polished and etched. $\times 2\frac{1}{4}$.

Fig. 7. Enlargement of upper central area marked on fig. 4. The main dark mass is a mixture of grains of olivine and troilite, not showing the peripheral scattering seen in fig. 5 nor any enclosed nickel-iron. The remainder is olivine crystals in nickel-iron. Polished and etched. $\times 2\frac{1}{4}$.

Fig. 8. Enlargement of lower left marked area, fig. 4. In this the chondrule of olivine and troilite grains is even more broken up than in fig. 5. Parallel bands of kamacite crossing the plessite areas are again conspicuous. This is a common feature throughout. Schreibersite grains are seen in contact with olivine in the upper left and lower right corners. Polished and etched. $\times 2\frac{1}{4}$.

Fig. 3

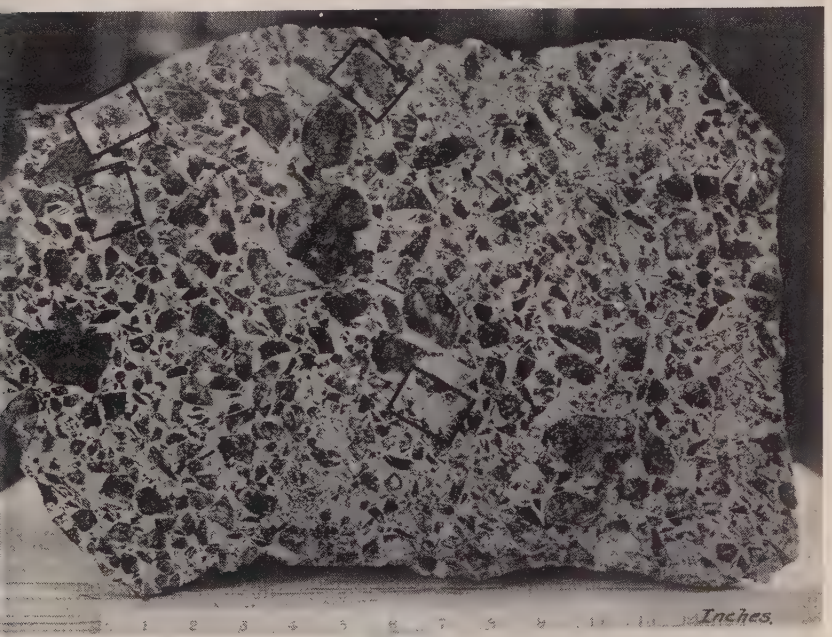


Fig. 4

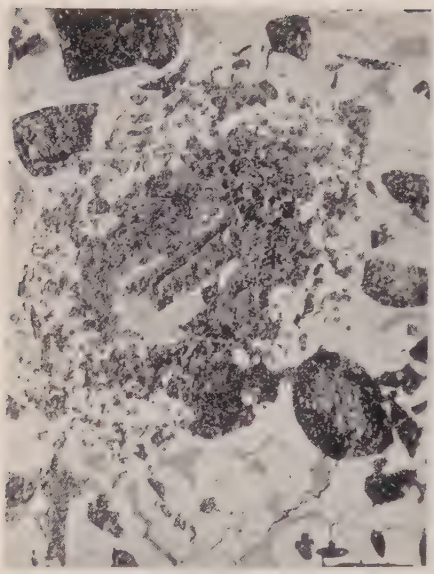


Fig. 5

Fig. 6

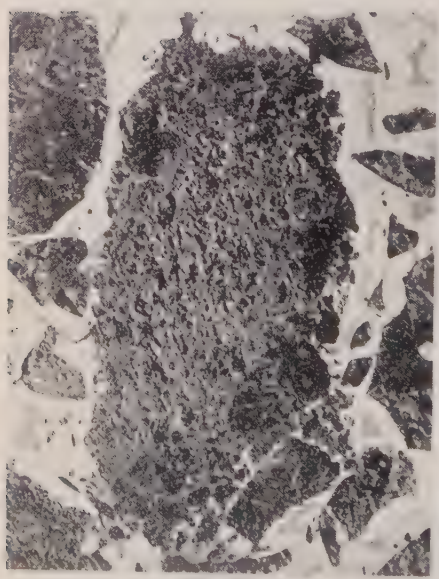
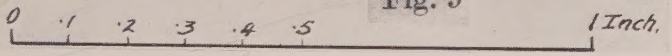


Fig. 7

Fig. 8

C. T. MADIGAN: HUCKITTA METEORITE

Fig. 9



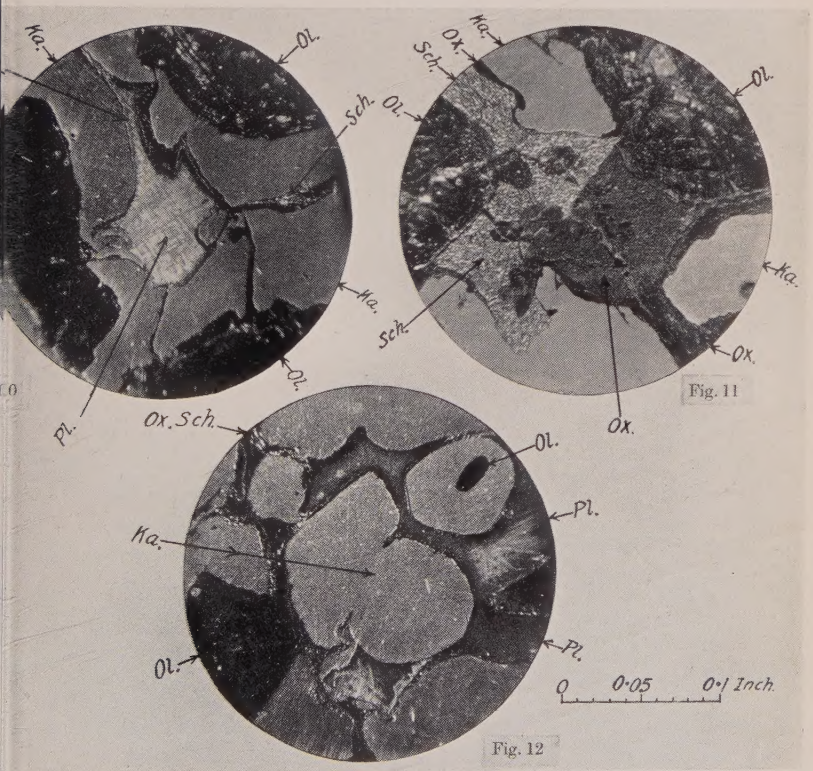


Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

C. T. Madigan: Huckitta meteorite

PLATE XIV, FIG. 9. A small piece, little over an inch long, prized off the main mass of the meteorite, polished and etched. The proportion of olivine (black) is here high. A higher polish was possible on this small piece, and Widmanstetter figures appear in the plessite, which is here lighter in shade than the kamacite grains, with a darker border of taenite. The areas marked with circles are enlarged in figs. 10–12. The specimen is more weathered than the areas in figs. 5–8, as it came from the outside of the meteorite. $\times 3$.

FIG. 10. A central plessite grain, with Widmanstetter figures and darker taenite borders, enclosed in kamacite and surrounded by black olivines. The cracks between kamacite grains are wider and filled with iron oxides. These lines of oxide often contain grains of schreibersite, as at the right. In the figs. 10–12, Ol. = olivine, Ka. = kamacite, Pl. = plessite, Tae. = taenite, Sch. = schreibersite, Ox. = iron oxides or iron-shale. $\times 8\frac{1}{2}$.

FIG. 11. Large grains of schreibersite in contact with olivine, and a central oxidized area. No plessite appears, as it is always remote from the olivine. $\times 8\frac{1}{2}$.

FIG. 12. Kamacite grains (light), embedded in plessite (darker) which shows traces of structure. The taenite borders to the plessite here darker and indefinite. Broader lines of oxidation, with schreibersite grains, upper left. $\times 8\frac{1}{2}$.

PLATE XV, FIG. 13. Polished slab of iron-shale. The brown-black oxides of iron here appear white and the olivines black. Bands of oxide can be seen crossing the olivines. Brighter schreibersite grains are seen towards the lower right and in the middle of the largest olivine, also a large grain on the lower left margin. A white grain of taenite shows up near the upper right corner. $\times 1{\cdot}8$.

FIG. 14. Photomicrograph of a thin section of iron-shale, showing the fractured but unaltered state of the olivine (white). The oxides of iron are opaque and black. $\times 15$.

FIG. 15. Enlargement of portion of the natural surface marked out in fig. 3. Olivines stand out in the rusty iron matrix. $\times \frac{1}{3}$.